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# CAN A DELIVERABLE-ORIENTED Project Management Approach be the Foundations for a LEAN APPROACH?

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ABSTRACT

Through lessons learned from the management of the conception and construction of the Large Hadron Collider (LHC) at CERN, Geneva, this article shows that a project management framework that is deliverable-oriented, DSM- and EVM-based, and developed in a collaborative managerial approach where all key contributors—so-called project engineers at CERN—are deeply involved, could undoubtedly set the foundation for a Lean project management framework.

## INTRODUCTION

The Lean concept, when it is applied in association with a management domain, shows the willingness of the practitioner to stop wastefulness. Project management does not escape a general quest to save. For smaller projects, stopping wastefulness is prioritised through the training of project managers. A project manager who correctly handles project management techniques has every chance of being effective and even efficient in the management of his projects. When projects are of a much larger scale, the competence of each of the key actors in terms of project management is not sufficient; the intrinsic complexity of the project calls for the production of an important quantity of information, whether it is descriptive technical information and demonstrative of the deliverable to be achieved, or programmatic information, such as project organisation, plans and schedules, financial and budget data, risk analysis, etc. Efficiency thereby passes through a controlled production and use of this mass of information. The engineering practices of large industrial projects recommend the creation of a project office. In other words, an ad hoc structure placed under the direct authority of the project manager, designed to, among other missions, produce part of the programming information and coordinate the handling of this information. For projects of several tens of millions of euros or dollars spread over several years, the existence of structures that involve dozens of people does not generally pose a problem.

Even less so as the strict respect of deadlines and budgets justifies the resources deployed to lead it. There are also large-scale projects for which the existence of such structures shall be reduced to a strict minimum. For example, publicly financed projects for which the Courts of Auditors or other financial audit bodies benevolently monitor the smallest of direct non-operational spending. This is somewhat the case for scientific equipment construction programmes. The laboratories that develop them have a double mission: to develop and construct equipment and, once it is operational, to use it. The development and construction of new equipment is only decided once an instrument has delivered consistent research results. The cyclical character *(project – operation)* of the activities of certain large scientific laboratories makes it difficult to have a permanent project office designed to respond to the needs of some large-scale projects.

CERN in Geneva cannot avoid this. It operates the biggest scientific instruments that humanity has ever created. The development and construction of the most recent of which, the Large Hadron Collider *(LHC)*, took more than 12 years, costing more than 7 million euros. Thousands of people, physicists, engineers and technicians contributed to its realisation. In many respects, this instrument shall provide the scientific community with the means to experimentally verify the validity of several theories of particle physics. Its size: nearly 27 km of perimeter buried at a depth of 100 m. Its functioning temperature: 1.85 K *(approx. –271 °C)*, which possibly makes it the coldest object in the universe. The magnetic energy stored in its cryogenic magnets surpasses a dozen gigajoules, equal to the kinetic energy of an A380 Airbus at cruising speed. The weight of the biggest of its detectors *(CMS)*, installed at one of the four collision points, is nearly 18,000 tonnes, equivalent to twice that of the Eiffel Tower. The quantity of information generated for the scientific community: approx. 15 petaoctets *(15 million gigaoctets)* are collected and recorded annually. Since its commissioning in 2010, physicists are more than happy and the "physics" it enables is most promising. In summer 2012, the premise of the confirmation of the so sought after existence of the Higgs Boson was announced.

Several choices directed the project management: the technological challenge had to be translated into an effort focused on the technical dimension of the project; its administrative needs should never constitute a hindrance or get in the way of the scientists and engineers who had the difficult task of finding innovative solutions to the myriad of problems brought about by the development of this particle accelerator. Less than two dozen people took turns to manage the project *(accelerator and infrastructure)* for the tasks related to project planning, economic control, risk monitoring, management of the configuration and technical information, all of which throughout the 15 years of the development and construction of the LHC. To meet this challenge, some strategic choices were made: maximal use of the internet *(recalling that the World Wide Web was developed at CERN at the end of the 1980s, initiated by an already globalised CERN scientific community, in response to information sharing problems)*.

If the project management system of the LHC had to be summed up in a few key words, the adjectives "collaborative" and "participative" would certainly be the best suited. The idea was, therefore, to delegate a maximum of management tasks to the hundred "project engineers": the electronic technical information management was put in place at the same time the project started, since it has become a PLM tool; operational planning within the fixed time limits of the coordination schedule; and periodic progress reporting through a dedicated EVM-based project control portal. CERN was certainly *avant-garde* in its use of a "project management 2.0" system.

The expression "2.0" was attached to the word "Web" by Dale Dougherty in 2003. His intention was to increase the simplicity and interactivity of the World Wide Web. Since, this expression has been attached to many concepts that show their authors' willingness to shift the reclusive practices of specialists to more collaborative approaches. "Project management 2.0" demonstrates this intention to give much more room to project contributors in planning exercises and notably project control, using as best as possible the functions of the World Wide Web. "Web 2.0" has both its promoters and detractors. The latter denounce the anarchy and chaos within it, without omitting the *infobesity* that sometimes strains the acquisition of sought-after information.

The project management approach used for the development and construction of the LHC integrates this willingness to allow the ensemble of key participants to actively take part in the process of progress reporting, but within a channelled framework in order to overcome the chaotic agonies of "Web 2.0". Without a doubt, the conception of a planning and project control system supported by a deliverable-oriented approach allowed this to happen.

The subject of this article is at least fourfold: describe the collaborative project management system that CERN conceived and developed for the LHC project; understand the difficulties encountered and the provisions to overcome them; offer some ideas to elaborate the functionalities that the CERN and the LHC were not able to put in place; and finally, in the guise of a conclusion, list some suggestions for a "manifesto for a more collaborative project management".

## 1. The collaborative project management system of the LHC project

Following the project management triangle *(performance – costs – delays)*, the projects preferentially come under one of the three categories. Those with deadline obligations, for which the due dates shall imperatively be respected. Event projects typically belong to this category. Projects with cost limitations in which the project team has use of resources allocated to it and shall do its utmost to produce the best possible result in the shortest time, and without envisaging the least budgetary additional charge. Those projects with a performance obligation for which it is fundamental that the end result be achieved and, in order to meet requirements, some cost overruns and reasonable delays are acceptable.

The LHC project definitely comes within this last category. At the beginning of the years 2000, in an address to staff, the Director General of CERN formulated this demand in the form of wit: in the event that the LHC project would be a few months late, five years after its completion, the incident would be forgotten. In the event of a reasonable increase, five years after its completion, the incident would also be forgotten. On the other hand, if the outcome of the accelerator did not reach the level of performance required, the memory of such a failure would stay engraved in everyone's minds for a very long time and would taint all new projects. Because of this, an important part of the project management effort was based on the maximisation of the technical success of the project. In the end, the future agreed with this managerial demand.

Before even its approval, it was publicly known that the project constituted a major technological challenge and that a number of very innovative solutions needed to be found in order to find satisfying technological solutions for problems for which only rough solutions existed. To encourage the emergence of these solutions, the project manager decided to promote a managerial framework that was not too constraining so that the numerous project engineers—the generic term given to some 300 applied engineers and physicists with the responsibility to develop the constituent systems of the accelerator and the associated technical infrastructures—could exercise their creativity without being perpetually impeded by reporting demands.

It was only at the end of 2002, when the project had already more than six years on the counter, and an external audit predicted higher expenditures than planned, that the LHC project leader sought to implement a reliable and reactive control system to the project. The project engineers were definitely not inclined to accept such an arrangement. One would also have to be creative to conceive such a trustworthy and reactive control system, implementing Lean principles. It goes without saying that the control system had to depend on the EVM approach. But how to put into practice such an approach, and at the same time allow project engineers to measure the progress of their activities and avoid the "90% syndrome"?

### From the "90 % Syndrome" to the Concept of "Deliverable"

An interesting study carried out by Ford and Sterman (2003) showed that in the absence of a clear reporting mechanism for the physical progress of their activities, managers are tempted to report the physical progress of their activities linearly proportionally to time elapsed, and do so until the 90% mark has been passed. The remaining 10% then takes much longer to carry out! The authors described this bias as the "90% syndrome". This study also showed that it was even more important that the project be of scale and the project teams distributed.

No commercial project management software package had really been designed to get round this bias. Their deployment assumed the recruitment of a dozen project controllers with the mandate to verify the truth of progress in advanced physics. The decision was then taken to proceed to some internal software development. Among the requirements, the operational planning and scheduling was delegated to the project engineers, and the periodic recording of the earned value. Then, the "90% syndrome" was overcome by putting in place a form of deliverable-orientation.

The term "deliverable" is ancient. The online etymology dictionary states that it appeared already at the end of the 18th Century. At the end of the 90s, Patrick Howard instigated the adoption of the term in project management *(Howard, 2005)*. The arrival of this new concept—some might say a change in paradigm—resulted in a simple assessment. Following project management good practices, e.g. those written in A Guide to the Project Management Body of Knowledge of the Project Management Institute *(2003)*, the project manager shall build his management system around a WBS *(work breakdown structure)*. This structure takes on a tree form in which the ultimate elements are the basic activities of the project. These good practices maintain that the progress of the project results from the aggregation of the progress of each of the basic activities. An activity, whose physical progress is 100 % is by definition completed. However, an activity that is supposedly completed by the person who is responsible for it is not necessarily seen as such by those that shall use the result. The notion of "deliverable" came about in the 90s as a loophole to this weakness, and therefore considered in the LHC project control system to avoid the "90% syndrome".

### Systematisation of the Notion of "Deliverable"

Even if the notion seems well anchored in the good practices of project management, it is nonetheless not yet a mature concept and several questions remain. Is a deliverable comparable to a product? Do all the activities necessarily need to produce deliverables? What of the numerous projects whose ultimate results are of an intangible nature?

The notion of deliverable differs from that of the product in so far as all deliverables are based on a product whose degree of completion is defined. For a product that, for example, is a technical system, the successive deliverables that can be associated with it are the examined system, the bought system, the delivered system, the installed system, the tested system, etc. If we associate one or more deliverables with an activity, it becomes obvious that the appreciation of progress becomes more objective.

All activities shall therefore produce deliverables. This assertion is easily understood for projects where the results are tangible, for example, the construction of a building, the equipping of a factory, or the development of a new product. It is certainly less obvious for projects where the results are of a more intangible nature, such as the reorganisation of a service, the preparation of an event, or the development of a new service. Experience shows that if these projects have results of an intangible nature, they are necessarily carried out in relation to tangible elements such as documents *(business process descriptions, procedures and instructions, etc.)* and physical means *(offices, furniture, machines, etc.)*. Also, we can safely assert that any project activity shall produce deliverables, whether the project is of a tangible or intangible nature, and that its activities aim to produce either physical or more immaterial results.

There are, nevertheless, project activities that consume resources, but without necessarily producing deliverables, for instance the *elementary activity* that consists of managing the project. To get around this bias, standards such as the ANSI #748—formalising the EVM *(Earned Value Management)* approach—allows a project to have one or several so-called *level-of-effort activities* in order to accommodate a few essential duties, that necessarily consumes resources, but for which it is difficult to identify clear deliverables.

Some may say that the addition of the concept of deliverable brought a little more complexity to the project management model, which is true. But when a model is too simple to correctly depict reality then there is a need to find a more efficient model. This new search for efficiency often involves the addition of sophistication.

### The Aggregation of Physical and Economic Progress Through the EVM Approach

Once the problem posed by the objective reporting of physical progress is resolved, the efficiency of the project control system should produce answers to the three main subjects preoccupying the project stakeholder which include: the capacity to produce the expected results, and the production of these results on schedule and within budget. The LHC project management team did not escape these considerations.

What some call *project control* brings answers to the second and third subjects of preoccupation that are the respect of deadlines and the budget *(Fleming & Koppelman, 2000)*. A physical progress based on a deliverable approach, combined with an updated Gantt diagram are sufficient to show the feasibility with respect to deadlines. The comparison of costs incurred and time spent with respect to budgets are also sufficient to demonstrate the feasibility of a project with respect to budget.

One shall recognise that for a long time this type of reporting was sufficient to win and retain the trust of project stakeholders *(Christensen 1998)*. However, such an approach raises several biases when the actual progress records, following both perspectives, different from the planned situations. A project report can highlight actuals that are less than those planned, jointly with technical progress in conformity with plans, but does this mean that the situation is satisfying? Experience shows not *(Webb 2003)*.

## C/SCSC and EVM Approaches

The approach that enabled this difficulty to be overcome was born across the Atlantic at the end of the 60s. Noting far too late the detrimental deviation in big weapon programmes, the United States *(US)* Department of Defence decided to impose a formal reporting framework on all projects that benefitted from large public financing. This project control model was given the name C/SCSC, the acronym of *Cost/Schedule Control System Criteria (Fleming & Koppelman, 2000)*.

The idea is basically simple and wise. Before the start of any project, the project team is asked to describe the rhythm at which it should earn value. In other words, the variable cadence at which the physical progress of the project should advance. Once the project has started, the project team follows its progression by reporting both the valued physical progress, and the cost incurred and time spent. The comparison of physical progress to planned progress on the one hand, then to actual costs on the other hand, provides a more pertinent information with regards to the "health of the project".

Until the end of the 80s, the use of C/SCSC in projects was still relatively confidential. Only large-scale public American projects used them, as they were compelled to do so by their stakeholders. Why did so few projects use it if it is qualified, as mentioned in the previous paragraph, as simple and wise? There are several reasons, including:

- US military standards, and particularly those related to management, are perceived heavy to implement and then to use;
- more generally, all management tasks are perceived as costly and very often not cost effective;
- the proposed four-letter long acronyms could create some confusion (see Table 1);
- finally, on the basis of the principle "a happy life is a discreet one", why be transparent and have stakeholders meddling in project affairs?

A shockwave in the democratisation of the C/SCSC was felt at the end of the 80s with the arrival of project management software programmes for micro-computers. But projects only began to appropriate this technique from 1996 onwards when the CSCS/C American military standard became a join *American National Standard Institute (ANSI)* and *American Electronic Industry Alliance (Abba 1997)*. At the same time, some changes also occurred:

- the name of the concept C/SCSC was renamed **Earned Value Management** and popularised under the acronyms EVM in the US (and EVA for **Earned Value Analysis** in the United Kingdom);
- the three main parameters of EVM received a more easily remembered and less ambiguous denomination (cf. Table 2).

Since the beginning of the 90s, EVM as a project reporting methodology received a lot of attention from standardisation bodies. The two main standards are ANSI #748 and the *Practice standard for Earned Value Management (PMI 2005)* of PMI.

| Acronym | Denomination |
|---|---|
| BCWS | Budgeted Cost of the Work Scheduled |
| BCWP | Budgeted Cost of the Work Performed |
| ACWP | Actual Cost of the Work Performed |

**TABLE 1.** *Main parameters of C/SCSC*

| Acronym | Denomination |
|---|---|
| PV | Planned Value |
| EV | Earned Value |
| AC | Actual Cost |

**TABLE 2.** *Main parameters of EVM*

EVM is mostly based on principles full of common sense *(Kim et al., 2003)*:

- before the project begins, give the rhythm at which it will (or should) **earn value**. In other words, give the periodic planned physical progress that should be obtained;
- when the project is on-going, record the **effective value earned**, and compare it with the planned one.

This information alone is not sufficient to realise the efficiency of the progress accomplished. In order to keep a watchful eye over possible abuses, EVM also takes into account the cost incurred and time passed in order to create the returned earned value.

Before a project starts, the rhythm at which it shall progress shall be defined: the PV *(planned value)* curve. PV is not a constant value, it evolves with time. Also, it is more meticulous to express it as a function: PV*(t)*.

**Figure 1** illustrates all that has been stated. Time runs from left to right; the accrued value is expressed in resource units that follow the vertical axe. In this figure, $S_{project}$ marks the planned start date of the project and $F_{project}$ marks its planned finish date.

This PV($t$) curve is established by adopting a Cartesian approach, that of the WBS which was mentioned earlier:

- decompose the project into basic activities;
- attribute a PV(t) to each of the basic activities;
- aggregate the basic functions to obtain the project PV(t) curve in its totality.

The budget at completion *(BAC)* is another concept specific to EVM. Let's recall that a project is defined as a complex system of contributors, of means and of actions, constituted to provide a response to a need *(AFITEP, 1992)*. The term "complex" was most certainly retained to describe the intrinsic speculative character of a project. The cyberneticists hold complex things for entities that can be described in their whole, but for which it is impossible to assign precise and definitive properties to the elements that constitute them. The concept of the "black box" was put forward in order to realise the difficulty of describing their content. A project is therefore speculative by nature. It necessarily contains a part that is unpredictable, and that the ensemble of participants is obliged to handle. For instance, project risk management aims at taking into account this lack of predictability so that the occurrence of unforeseen events do not jeopardise the project *(NDIA, 2005)*.

The promoters of EVM have certainly taken this into account by considering that a team receiving a project mandate shall create a reserve and/or a temporal budget in order to prepare for the unexpected. The importance of providing these reserves is based on the more or less speculative character of the project. In the context of the LHC project, and of the conception of its project control system, the dimensions of this reserve were quickly eluded! The project sponsors approved its construction on the condition that its cost be optimal. In other words, without reserve. The consequences of this decision were quickly felt. They will be discussed in the next section.

The earned value *(EV)* is defined as the budgeted cost of work actually accomplished at a reporting date. Let's call $T$ this date. Because the EV curve is obtained by positioning the successive points along the time axis, it is preferred to note $EVT$ as the earned value of the project on date $T$. The earned value $EVT$ is obtained by accumulating the $EV_i\ T$ of each of the $i$ activities of the project. In terms of basic activities, three cases can occur:

- either the activity i is finished; its value earned is equal to its budget : $EV_{iT} = BAC_i$;
- either the activity i has not started; its earned value is zero: $EV_{iT} = 0$;
- either the activity i is on-going: its earned value is proportional to the physical progress (let us call it $\varphi_i$: $EV_{iT} = \varphi_i \times BAC_i$).

The physical progress $\varphi_i$ of an activity is a value between 0 and 1: 0 or 0 % for an activity that has not started, and 1 or 100 % for a completed activity.

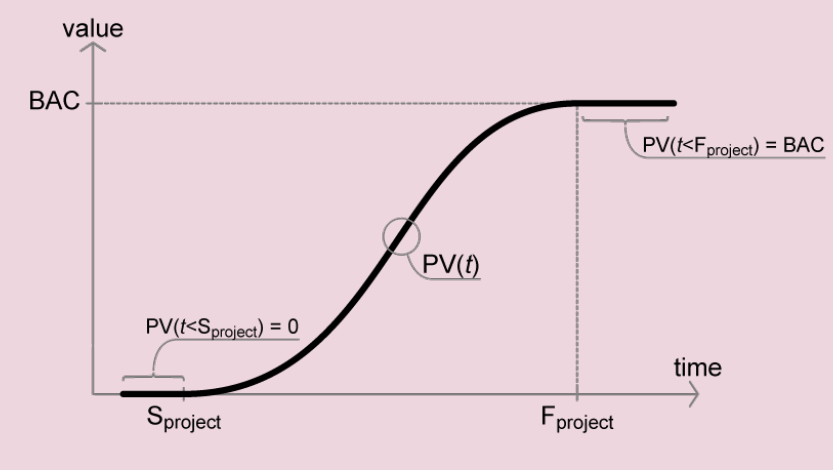


**FIGURE 1.** *PV(t) curve*

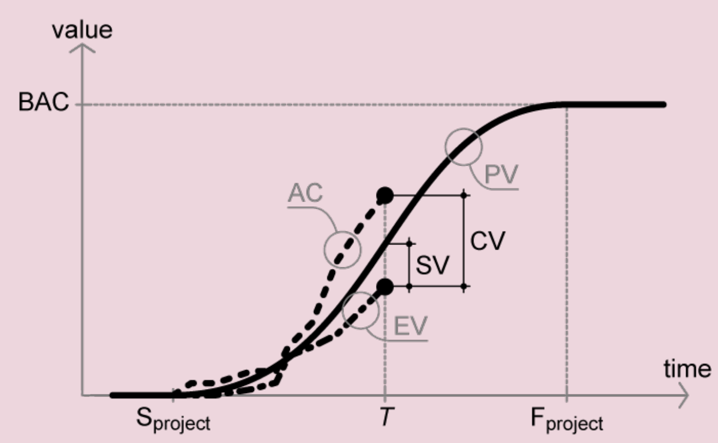


**FIGURE 2.** *PV(t), EV(t) and AC(t) curves; schedule variance $SV_T$ and cost variance $CV_T$.*

Once the $EV_T$ is plotted, three situations can occur:

- either the $EV_T$ is on the PV(t) curve: $EV_T = PV(T)$; the project is neither ahead of schedule nor behind schedule, it is just on time;
- either $EV_T$ is under the PV(t) curve: $EV_T < PV(T)$; the project is thereby late; the earned value is lower than that planned;
- either $EV_T$ is above the PV(t) curve: $EV_T > PV(T)$; the project is thereby ahead of schedule: the earned value is higher than the planned value.

The advance or delay can be measured by the difference between $EV_T$ and *PV(T)*. In EVM jargon, this difference is called schedule variance *(SV)*: $SV_T = EV_T - PV(T)$. If the variance is positive, it means that the project is ahead of schedule. If it is negative, the project is late *(cf.* **Figure 2**.*)*.

The actual costs *(AC)* are defined as the actual spending or that engaged at the progress report. To register this information, the project shall have a means to take into account all the expenses assignable to the project, including time spent. If *T* remains the date at which the progress report/situation is established, $AC_T$ is obtained through the simple transfer of amounts from accounting ledgers and/or time spent records.

Once $AC_T$ is transferred to *PV(t)* and *EV(t)* curves, three situations can occur:

- either $AC_T$ and $EV_T$ are merged: $AC_T = EV_T$; the project is not, at date **T**, either showing a underrun or overrun; its physical progress is therefore at the anticipated cost;
- $AC_T < EV_T$; the project is underrunning: its physical progress costs less than planned;
- $AC_T > EV_T$; the project is overrunning: its physical progress costs more than planned.

The economic health of the project can be quantified by making the difference between $EV_T$ and $AC_T$. In EVM jargon, this difference is called the cost variance: $CV_T = EV_T - AC_T$. If the difference is positive, it shows an underrun; if it is negative, an overrun *(cf.* **Figure 2***)*.

### Integrating the Concepts of "Deliverable" in EVM

Basically, the integration of this notion in EVM does not raise a particular problem. For a given activity, one or more deliverables are identified and planned accordingly . On date *T*, the physical progress of the activity is determined by controlling which deliverables have been achieved, then by counting them against the total amount of deliverables planned for the activity.

The objectivity of the physical progress measurement, and by the way that of the earned value, relies on the fact that it is not a raw percentage that is expected from the project engineers, but a count of achieved deliverables. The objectivity of this approach is undeniable. However, very few, if any at all, commercial project management software includes such a functionality!

The information related to progress control is not limited to the recording of achieved deliverables, and therefore actual finish dates of project activities. A good coordination implies the recording of actual activity start dates. In order to circumvent a possible collection of varied temporal information—information related to the activity *(actual start dates)* or deliverables associated with activities *(actual end dates)*—it was decided to record start information at deliverable level by means of zero-weight deliverables featuring start dates.

## 2. Difficulties encountered and recommendations to overcome them

Very few are the management system modelling exercises that produce a satisfying result as from their very first version. That which was conceived for the LHC project did not escape the rule, although it was possible to improve it. The aim of this third section is to point out the difficulties and to offer some solutions to overcome them.

### The Layout and Size of the Activity Portfolio

For projects of rather small sizes, the implementation of the above would be amply sufficient and would not raise particular issues. For bigger ones like the LHC project, this framework presents a few limitations. The most limiting factor is the size of the activity portfolio. Project management literature is not particularly loquacious in terms of the optimal size of a project's activity portfolio. Some practitioners suggest that over 300 or 400 activities, it is nearly impossible to envisage a proactive control system. To bypass this limit, Morris *(1994)* recommends a *rolling wave scheduling*. This approach aims at building a portfolio made of macro-activities and then, as the project progresses, detailing those macro-activities that appear in a close temporal space: the planned macro-activities that start under several weeks are broken down into as many coordination activities as necessary. By proceeding this way, we avoid building a portfolio of planned activities that is too large, but without restricting the required granularity for a good coordination. It is also what the EVM standards recommend by distinguishing *work packages*, achievable in a short timeframe, and *planned packages* that have a medium and long deadline.

Nearly 10,000 activities were described to ensure control of the LHC project. Two main reasons explain why there was such a large portfolio. The first is the fact that the exercise of identifying activities was confined to each of the project engineers. Most thought they were doing the right thing by trying to pair supply contract delivery deadlines with work through the creation of a unique deliverable activity for each. Some 300 contracts were attributed to industrial firms.

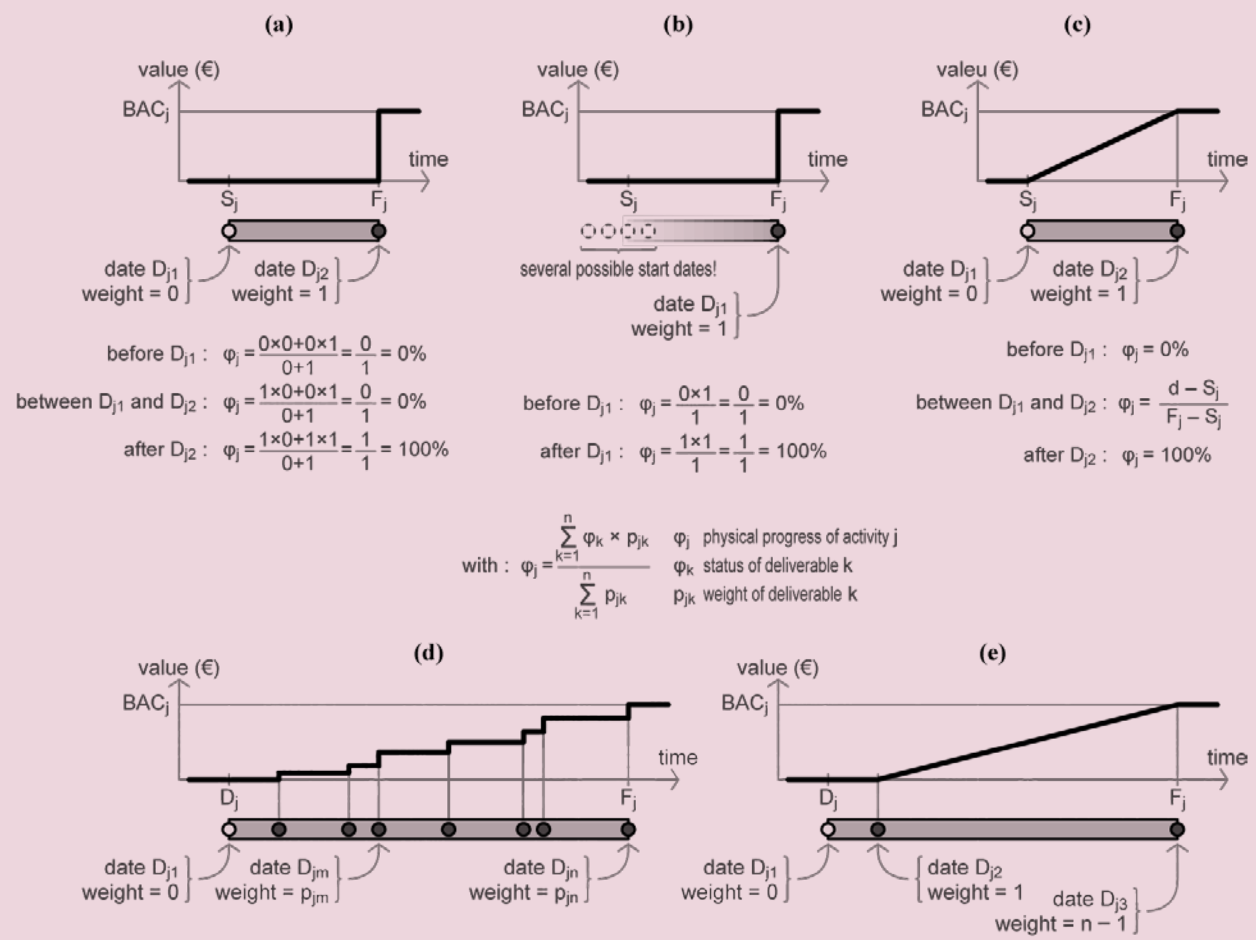


**FIGURE 3.** *Activity typology: (a) standard activity; (b) outsourced activity; (c) level-of-effort activity; (d) complex activities with several deliverables (e) repetitive activity or activity with a linear development.*

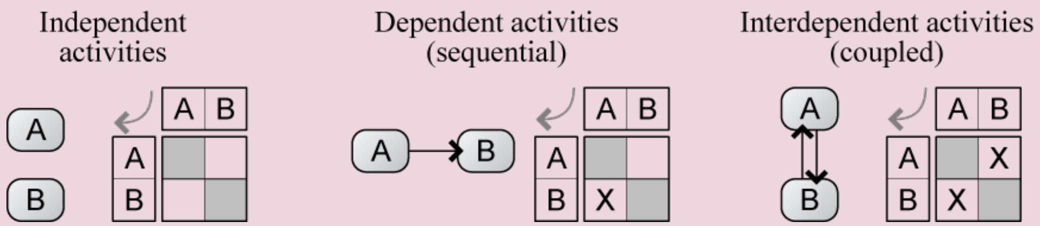


**FIGURE 4.** *The three types of dependencies between activities according to DSM.*

| Relation | Interpretation | Gantt-chart like illustration |
|---|---|---|
| A b B | A before B | A |
| B bi A | B after A | B |
| A m B | A meets B | A |
| B mi A | B is met by A | B |
| A o B | A overlaps B | A |
| B oi A | B is overlapped by A | B |
| A s B | A starts B | A |
| B si A | B is started by A | B |
| A d B | A is during B | A |
| B di A | B contains A | B |
| A f B | A finishes B | A |
| B fi A | B is finished by A | B |
| A = B | A equals B | A<br>B |

**FIGURE 5.** *The 13 relationships of temporal dependence between two intervals.*

With around fifteen deliverable deadlines per contract, the number of activities was quickly substantial! In addition to the manufacturing activities, installation difficulties were added: tens of thousands of pieces of equipment were to be transported to and installed in the 27 km long by 10 $m^2$ cross section tunnel. The second reason is most certainly related to the speed with which the project control system was put in place. Each of the project engineers got involved in the mission of description without being sufficiently trained to do so. Some, who thought that they were doing the right thing, generated a sub-set of activities that was too big. Facing a done deed, it was not easy to ask the project engineers to go back to the drawing board and produce a more synthetic sub-set of activities.

The problem of an excessive activity portfolio size could have been avoided had there been a more in-depth descriptive model of the activities. If a "standard activity" is appropriately modelled by means of two deliverables: one of a zero-weight featuring the start date, and a second one featuring the finish date of the *(cf.* **Figure 3** *(a))*, this modelling is either too restrictive or on the contrary excessive for some activities! A similar pattern goes for level-of-effort activities *(cf. Figure 3 (c))*.

The activities for which this modelling is insufficient are activities that intervene at the very beginning of the project *(conception activities)* and at its end *(integration and commissioning activities)*. The "V-modell" of the life cycle of a project perfectly explains this phenomenon. These activities are generally imprinted with a certain complexity. As much as they aim to produce a number of deliverables, it is not easy to precisely allocate part of the activity budget to each of the deliverables, and the weighting of deliverables also needs to be dealt with *(cf. Figure 3 (d))*.

Other activities for which this modelling is not well suited can typically be the so-called outsourced activities. In other words, those activities performed by others—i.e. suppliers or contractors—through commercial contracts. If it is expected that the suppliers or contractors should deliver a part of a contract on a given date, this information shall necessarily figure in the contract. But it is highly probable that, in a result-oriented contract, the starting dates of the activities are not specified. Hence, for outsourced activities, only the dates associated with deliverables are known, and by the way only one deliverable is featured *(cf. Figure 3 (b))*. Even if these activities may look like milestones on a Gantt chart, they definitively are activities.

Large industrial projects are very often characterised by the fact that they comprise repetitive activities or activities with a linear development. For instance, in the framework of the LHC project, the manufacture and assembly of 1200 cryodipoles formed a set of repeated activities, as many times as there was such equipment to build. Their installation in the 27 km of tunnel formed an important set of activities with a linear development. Their specificities shall be considered to efficiently model these set activities *(cf.* **Figure 3** *(e))*.

An enhanced typology of activities would certainly have led to a more concise portfolio of activities. But this action alone would not necessarily have been enough. At the beginning of the LHC project, Bachy and Hameri *(1995)* had suggested adhering to a deeply systematic approach in order to identify the constitutive activities of a large scale project: describe the product *(aim of the project)* through a tree structure *(the Product Breakdown Structure or PBS)*; from this structure derive a second one that describes how to assemble the many components *(Assembly Breakdown Structure or ABS)*, then build the WBS of the project. In a more recent article written in the context of the ITER project *(www.iter.org)*, Van Houtte *et al. (2012)* recommend preluding this approach with a reflection on the functions that the product *(aim of the project)* shall satisfy by starting a structuring exercise with the elaboration of a *functional breakdown structure (FBS)* from which the PBS will be deduced. The experience acquired through the LHC project tends to confirm the vital character of a segmented approach.

## Activity Sequencing

As much as the collaborative approach was used to identify constituent activities of the project, the sequence of activities remained centralised in the interests of the project management team. It is undeniable that planning approaches based on networks – critical path method, precedence method – made their mark. However, carrying them out within the collaborative management framework wanted for the LHC project proved delicate. The problem that appeared during the conception of the control system was finding an integrated arbitration as soon as several project engineers had antagonistic opinions with regards to the sequencing of activities. A project engineer could typically have hoped that his activities be subsequent to that of his colleagues, while the latter would want the same. By strictly applying planning methodology principles as stated before, these contradictory wills would have led to loops, and therefore the impossibility of building a schedule for the project.

Two methodological approaches can bring some responses to this difficulty: the *Design Structure Matrix* or the *Dependency Structure Matrix (DSM)* on the one hand, and Allen's interval algebra on the other.

DSM is a matrix analytical approach that was introduced at the beginning of the 80s *(Steward 1981)* to solve problems of interdependence between activities. It was only a dozen years later that it became of interest, under the instigation of Stephen Eppinger at MIT, for solving multiple problems linked to the development of new products *(Pimmer and Eppinger 1994, Browning 1998, Eppinger 1997, Smith and Eppinger 1997)*. Some see it as the most powerful tool for solving complex interdependence problems or links between activities. **Figure 4** gives an illustration of three types of interdependence between two activities offered by DSM.

Allen's interval algebra was also introduced at the beginning of the 80s *(Allen 1983)* in order to propose a time-based reasoning framework, not on dates but on intervals. This algebra defined 13 possible relationships of dependence between two intervals *(cf. Figure 5)*. It also offers a composition table that facilitates the logical reasoning of described events through these 13 relationships. Allen's algebra can be used in particular to check if a set of dependencies between several activities is possible or not. For example, a good use of the composition table would show that the two assertions “Activity A shall happen before Activity B” *(in other words A b B)* and “Activity B shall be overlapped by Activity A” *(in other worlds B oi A)* are incoherent. In DSM, the treatment of this assertion would only lead to saying that Activities A and B are linked; that there exists an interdependence between the two activities.

Unfortunately, problems of computational tractability rapidly dominated the analytical performances of Allen’s interval algebra. Nevertheless, research showed that this algebra could be interesting in the domain of project planning *(Hussain 2000, Smith et al. 2000)*. Other practical applications of this algebra include judicial investigations where it was used to put into perspective several depositions by identifying the compatible events between them and those that are not, and through this bring out the possibly false declarations.

DSM or Allen’s interval algebra, which of the two is preferred in the context of a collaborative management project? The choice of one or the other depends on the collaborative approach that the project management team intends to put in place. If the duty to describe activities is left to each project engineer, i.e. those activities that she/he and her/his team intend to carry out, as well as those that she/he envisages for her/his project engineer colleagues, then Allen’s algebra appears to be well suited. The analysis of this mass of information consists of searching for the common activities among the portfolio propositions, and then comparing each one to see if the proposed dependency assertions are plausible or not, and this in order to bring out those sequences of activities that are most likely to lead to a consensus. Nevertheless, this approach presents several difficulties. The first is the search for identical activities in the diverse proposals of activity portfolios. In order to be efficient, it seems imperative that each one be labelled in a coherent way in order to allow for reliable matches. The problem that all project planners experienced was related to the prescriptive model of naming activities. The second was the coherence of the proposed activity portfolios. It is very likely that each of the contributors to this collaborative exercise would be inclined to describe his own activities in a very clear manner, but more elusively those of other project engineers for which he is either not the holder, or does not have the required competence to pertinently identify them. The third is the cost of this collaborative planning exercise. Even if planning efforts lead to cost saving, to ask all project engineers to take part in such an exercise seems difficult to justify. The limit of computational tractability of the aforementioned algebra constitutes the fourth and final reason to prefer DSM.

In practice, what form could the exercise of collecting information related to the potential constraints between activities take? The collaborative planning exercise would consist of two phases. The first phase, during which the project engineers would be asked to identify the macro-activities that they are deemed responsible for. Some metadata should complete the description of each one: the required resources *(logistical constraints)*, the deliverables that will be produced, a rough estimate of the completion period, and temporal constraints if needed. Only once this first phase has been achieved can the activity managers clearly define the potential constraints between macro-activities, as well as between deliverables. The registration of this information constitutes the second phase in the approach. As the constraints are registered, the macro-activities can be planned: the DSM algorithms can be used to identify conflicts, in other words clusters of activities that form cycles. The activity managers can then come together to find solutions to the problems of sequencing. The literature that deals with DSM proposes a number of solutions to problems that are often encountered. It is possible that a participant of this exercise does not find the predecessor activity that produces the deliverable*(s)* required to start one or more of her/his activities. In this case, each project engineer shall have the possibility of suggesting activities that are homologous to draft solutions for the difficulties encountered. These proposals shall be discussed with the concerned colleagues until a consensus has been found. It is only after all the participants of this planning exercise have recognised the consensual character of the obtained schedule, that the portfolio can be frozen to become the reference schedule towards which the progress of the project will be compared.

Even if Allen’s interval algebra is not an appropriate solution for the creation of a collaborative system for project planning, scheduling and control, this algebra shall not be eliminated from the project management toolbox too quickly! As much as this approach may seem difficult to carry out at a coordination planning and scheduling level, it can be very useful for the development of the project master schedules, which very often only consist of a few dozen macro-activities. Its use could be conceived within the framework of a so-called Delphi approach, for which the mandated experts would respond through Gantt diagrams that are then submitted to this algebra to find a consensus. To our knowledge, beyond the articles of Hussain *(2000)* and Smith *et al. (2000)*, no academic work has explored this question further.

### The Management Reserve of the LHC Project

Since 1994, the CERN Council, which approved the construction of the LHC, also confirmed the necessity for this project to be achieved at budget. In other words, the budget allocated to the project team was to be entirely distributed amongst macro-activities. In practice, supplementary budget allocations were deemed necessary and were granted as and when the project management requested them, after due justification of course. The reasons for these requests were multiple.  Some were external to the project to cope with changes to the economic and commercial context—inflation, price escalation of raw materials, the typical oligopolistic commercial environment and full order books that led to an increase in offers—and some internal to the project, to solve the numerous technical, technological and programming problems encountered throughout as developments progressed.

In the absence of a project management reserve, the project management team had to make great efforts, in contradiction with the principles of Lean, to find the required resources, to proceed with their reassignment of the activities that needed them, together with partial project rescheduling and rebaselining. The experience acquired on the LHC project undoubtedly confirmed the necessity to have a project management reserve clearly set up, as from the very beginning of the project.

How to size it? The exercise is not very easy, and rarely do people take risks in the field! For projects in the domain of construction, usually 15 % is put aside as reserve. This percentage is most likely inappropriate when outside of this domain. Beyond defining this percentage, some prerequisites are deemed indispensable. Actually, it is essential that all stakeholders of the project be fully conscious that:

- a project is by definition an activity that involves the unexpected;
- to complete a project, the project team shall dispose of reserves, equally in terms of budget and time;
- reserves are there to be used, partially or totally, if deemed necessary;
- the project management team shall have an authority as to their use;
- the distribution of residual amounts shall be defined at the beginning of the project: for example 50 % to stakeholders and 50 % to the project team.

## 3. Manifesto for a more collaborative project management framework

This manifesto is in some ways the conclusion to this article. The experience acquired throughout the LHC project led key participants of the project to believe that a collaborative project management framework constitutes the future of large-scale project management; this approach led to the development of a managerial framework that fell perfectly within the Lean approach. But in order for dozens, if not hundreds, of contributors to the project to get involved willingly in such project management exercises, while their daily concerns are more focussed on technological or scientific preoccupations, it is essential that the project management system be perfectly conceived, and in particular that project engineers spend as little time as possible on management tasks.

The aim here is not to produce an ideal functional specification of the project management system, but to bring out some conception elements that we feel are essential.

1. The activity identification process shall be separated into successive stages so that each person can progressively contribute to defining the project management framework:

- agree upon an appropriate strategy towards risk management and sizing of the project management reserve;
- produce in a collaborative way the functional breakdown structure of the project (FBS);
- still in a collaborative way, deduce the project product breakdown structure (PBS) from this FBS;
- then from this PBS deduce the higher levels of the work breakdown structure (WBS). Then, by means of a generic activity list, and through the intermediary of a matrix approach, define the size of an adequate activity portfolio (before even describing each of the activities);
- once the portfolio is sized, leave each of the participants of the exercise the care of defining each of the macro-activities for which they believe it legitimate to supervise their realisation. This definition includes the identification

of resources and a budget distribution, the identification of deliverables, the estimation of duration and a temporal pre-positioning on the basis of project master schedule.

A few iterations shall be sufficient enough to reach a coherent and consensual portfolio.

2. The process of sequencing activities shall also be separated into several successive stages:

- register the wishes related to macro-activity predecessors and successors;
- through the DSM, search for the antagonistic requests by identifying the clusters of macro-activities for which an arbitration is deemed necessary;
- for each one, ask the concerned participants to find a consensual outcome. This search can pass through the sectioning of activities, for example through the addition of intermediate deliverables that show partial completion states.

Repeat this process until all clusters disappear and a consensual planning and scheduling emerges.

3. The resulting consensual schedule is then frozen in order to become the project baseline.

4. Since the EVM approach is the most used and suited to appraise the progress of the project, periodically:

- the key contributors to the project are invited to record the time spent on the different project activities;
- the cost incurred shall originate from the accounting management system of the organisation and be affected to activities through the choice of a judicious budget codification;
- the effective physical progress of activities is collected by the key contributors through a simple information on the achievement status of deliverables.

With this information, the project management team has all the elements needed to calculate the global costs incurred, as well as their earned value, and can deduce the different indicators related to the health of the project and its possible evolution.

It is likely that undesirable events will disturb the running of the project. Of two things:

- either, the event moderately affects the completion of the project, in which case no specific provisions for the redeployment of activities and resources is envisaged. The EVM indicators take into account these small differences;
- or, the event more profoundly affects the project, in which case the concerned stakeholders need to decide whether to redeploy the resources or available time of the project management reserve, modify the activity portfolio and produce a new baseline.

With this last hypothesis, in order to stay loyal towards all stakeholders, the costs incurred, as well as the earned value, shall be analysed according to the baseline that was valid for the previous progress status and following the new reference submitted for the approbation of the project stakeholders. In order to stay credible, these rebaselining exercises shall stay exceptional and benefit from a convincing justification.

In view of this, we are convinced that a large-scale project can be managed very efficiently through the efficient transfer of managerial actions generally attributed to project management teams to the key contributors. In this way, we can justify the reduction in size of a project management team, without overloading the project engineers who would have undertaken a good number of management tasks. This approach is perfectly inscribed in the Lean management approach.

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