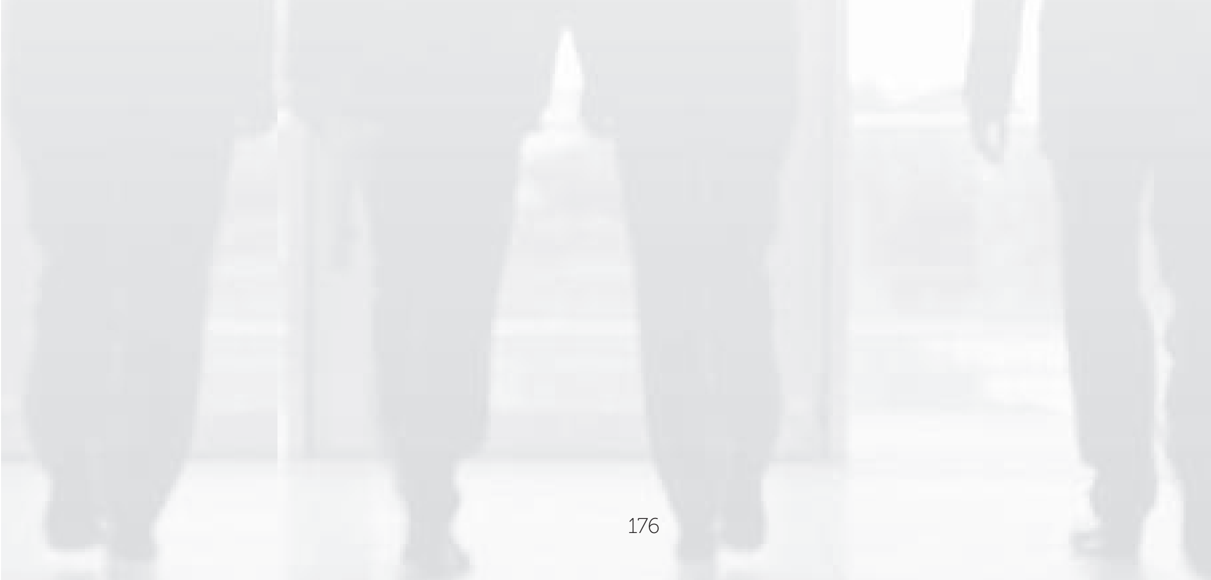
Chapter 10 | overview

In this chapter the basics of project monitoring and control are explained, including some straightforward examples to illustrate the most common methods being applied on projects. It becomes clear that adequate project controls are a critical part of project success and that the project controls team has an important role to play. Adequate control means applying the right level of control for each scope element and associated risks during the subsequent project phases.

Being the conscience of the project manager, the project controls team needs to provide reliable information for timely decision making. This requires input from many different disciplines and external parties that needs to be analysed, integrated and reported. To perform this essential task, the project controls team needs to proactively engage with the project team and various external stakeholders, while realising that they all have their own interest in measuring and reporting project performance.

This chapter starts by explaining how to establish the right cost and schedule baseline, followed by controlling the project as it develops. Next progress reporting, the role of the project controls team and the importance of effective communication is being described.

Chapter 10 | outline



Chapter 10
Project monitoring and control

by Maurits Gerver

10.1 | Introduction

Most project managers will at least feel somewhat uncomfortable when they are asked if they are fully in control of their project. Being risk-averse by nature, a project manager will immediately think about matters that could go wrong, wondering whether she might have missed an unidentified risk and of course think about the weak spots already known.
According to the online Oxford dictionary *control* can be defined as '*the power to influence or direct people's behaviour or the course of events*'. This is the essence of controlling a project, being able to influence the course of a project by knowing where to go, knowing how to get there and knowing which steps should be taken in case the project derails.

If a project is not in control, a variety of things can go wrong. Below some statements are listed that will sound familiar to most project managers:

- The agreed schedule to deliver the project was unrealistic from the start.
- The stream of scope changes during construction never seemed to stop.
- We have significantly underspent budget.
- It took months before producing at design capacity.
- The operational cost turned out to be much higher than predicted.

Realising that projects should add value to a business, the above samples illustrate that there are many ways to erode that value. This can be caused by poor definition of the initial premises, for example committing to an unrealistic budget or schedule. But it can also be caused by poor scope definition, lack of planning, or poor cost control. In the worst case a project gets out of control and the initial business value has vanished by the time the project is delivered.
As a project develops from initial business opportunity to design and engineering, construction and handover to the end-user, project controls mature accordingly. As the level of project definition grows over time project controls will be performed on a more detailed level.

The next paragraphs describe the key elements to control project planning and execution. They also discuss the impact that human behaviour can have on project controls, both from within the project controls team as from stakeholders outside the team.

10.2 | Cost estimating

10.2.1 Introduction

One of the most important elements to control during the lifetime of a project is cost, starting with providing the right cost estimates.

The cost estimate covering the initial capital investment, also called Capital Expenditure (CAPEX), is usually generated at the very beginning of a project, or even before project initiation, and is subsequently updated and detailed during project development. The estimate covering the operational cost, also known as Operational Expenditure (OPEX) or Revenue Expenditure, includes all cost incurred during normal operations once the project has been delivered. OPEX typically includes the cost of operations, maintenance cost, consumables and cost of sales. Although this chapter will primarily focus on estimating and controlling the capital investment, the operational cost is also an important input to the project economics and can be used to make trade-offs during design and procurement on the basis of lifecycle cost, also referred to as Total Cost of Ownership.

The Wind Farm

As Allwind will be responsible for the turnkey realisation and the 20 years' maintenance of the offshore wind farm, they should look into optimising the lifecycle cost. Trade-offs can be made between the initial capital investment (CAPEX) and maintenance cost (OPEX). While making these trade-offs there could be a potential difference of interest between Allwind and the owner's organisation. Allwind could aim at optimising their combined profit from the turnkey realisation contract and the maintenance contract, while the owner would like to minimise the lifecycle cost and optimise the availability of the wind farm.
For example if Allwind uses cheaper components they will reduce their CAPEX cost under the turnkey realisation contract, while the maintenance cost will likely go up. The owner could consider including specific performance targets in the maintenance contract, to incentivise Allwind for optimising the availability of the wind farm, while minimising maintenance cost. For example targets on wind farm availability, yearly maintenance cost or response time in case of an unplanned outage.

The quality of a capital cost estimate is critical, as it impacts the economics of a project and can determine the investment decision. Since funds and resources are constrained, a company can only invest in a limited number of projects, depending on their business cases. Poor cost estimates can either result in cancellation of economically sound projects, or in wasting money and resources on non-profitable projects.

In this paragraph the different classes of estimates and their specific purposes are explained, followed by describing a cost-estimate structure and the commonly applied estimating methodologies.

10.2.2 Types of cost estimates

There are many different names and classifications of cost estimates, depending on their purpose and required level of detail and accuracy. The estimate type or class is often related to a typical set of deliverables in a project development phase like design and engineering documentation, a project execution plan and schedule. The level of estimate accuracy depends on the level of project definition and is an indication of the degree to which the final cost outcome for a given project will vary from the estimated cost. Besides the level of project definition, the estimate accuracy also depends on a variety of factors like for example applying new technology, project complexity and quality of reference cost data.

Although there are many different cost estimate classifications used in the industry, the accuracy ranges and required supporting project definition are comparable. However the end usage of an estimate can vary per stakeholder. An owner's company could use an estimate for project sanctioning, while an EPCM contractor uses the same class of estimate to prepare a bid. Table 10.1 provides an overview of estimate classes, based on the Generic Cost Estimate Classification Matrix as developed by AACE International (AACE, 2011).

Table 10.1: Estimate classes

Estimate class	Level of project definition deliverables (% of complete definition)	Typical purpose of estimate	Typical accuracy range
Class 5	0 % – 2 %	Screening or feasibility	> ±30 %
Class 4	1 % – 15 %	Concept study or feasibility	±20 %
Class 3	10 % – 40 %	Budget authorisation or control	±10 %
Class 2	30 % – 75 %	Control or bid/tender	±5 %
Class 1	65 % – 100 %	Check estimate or bid/tender	< ±5 %

It is important to realise that an estimate is never a single number, but it comes with a margin of uncertainty or accuracy. Not seldom are cost estimate numbers treated as firm numbers, while people forget the underlying risks and uncertainties.

Next each estimate class and its purpose will be explained in more detail.

Class 5: Screening estimate

The purpose of a screening estimate, also called a subjective estimate (Lester, 2014), is often to provide a ballpark figure or order of magnitude number being used for strategic business planning, such as ranking of future investments. It enables management to prioritise projects by comparing, amongst other drivers, the economics of each individual project. A screening estimate is usually compiled even before project initiation, or during the first project development phase. The level of project definition and available deliverables are limited at this stage, hence the wide accuracy range. A screening estimate can be delivered relatively fast and does not require much effort to deliver.

Class 4: Concept Study estimate
The purpose of a concept study estimate can be to determine project feasibility, concept evaluation or to provide a preliminary budget. At this stage the project premises (e.g. objectives, key assumptions, technical premises, etc.) are frozen, concepts have been developed and the first engineering might have been completed to determine the technical design basis. For complex projects it is also common to assess the feasibility of multiple options, supported by multiple cost estimates to help management compare the concepts and select one. A preliminary budget might be required to move to the next project phase.
Since a class 4 estimate is still based on limited information, it has a fairly wide accuracy range and it still requires limited time and effort to deliver it.

Class 3: Budget estimate
The purpose of a budget estimate can be to support budget authorisation and/or project sanctioning. The estimate is based on typical project deliverables like front-end engineering documentation, a detailed project execution plan and a minimum percentage of firm quotes from vendors and service companies. The estimate has a better accuracy range and can even become the first control estimate against which cost performance is being monitored.

Class 2: Control estimate
A control estimate, also called an analytical estimate, provides the baseline for detailed cost control during project implementation. It can also serve as a tender or bid estimate, used to determine contract value. It is the most detailed estimate typically in place at the start of construction and requires rigorous management of change to monitor variations to the budget.

Class 1: Check or Tender estimate
Class 1 estimates are generally prepared for discrete parts of the total project rather than for the entire project. The parts of the project estimated at this level of detail will typically be used by subcontractors for bids, or by owners for check estimates (bid checks, claims, change orders, etc.). Depending on the cost changes, it can be used to update the control estimate and to establish a new baseline for cost control. A project definition level of 100 % will normally only be reached upon project completion, at which the actual cost are known.

10.2.3 Cost estimate basis and elements

The basis of an estimate is often described in a Basis Of Estimate document, stating the purpose of the estimate, project scope, pricing basis, allowances, assumptions, exclusions, cost risk and opportunities. It documents the communication and agreements that have been made between the estimator and other project stakeholders about the cost estimate basis (AACE, 2013).

Building up the estimate requires input from the entire project team and even from outside the project team. All disciplines are involved in defining the scope of work and the cost estimator needs to interface with all of them to have a good understanding of this scope of work. In practice it still happens too often that an estimator develops the estimate in isolation, without proactively interfacing with the appropriate stakeholders. This can lead to an incomplete or misunderstood basis of estimate and ultimately in surprises when the estimate is being released.

A Basis of Estimate document helps to document the collective understanding of the scope of work, schedule milestones, key risks and underlying assumptions that impact the cost estimate. Therefore an estimate should always be accompanied by a Basis Of Estimate document as a reference.

Next it is explained how an estimate can be structured and which cost elements are typically included.

Work Breakdown Structure (WBS)
A WBS defines the hierarchical decomposition of tasks and subtasks. A high-level WBS will be produced at the very beginning of a project and will become more detailed as the project matures. The objective of defining a WBS is to be able to control the project by allocating resources (human, material and financial) and giving time constraints to each (sub)task (Lester, 2014). So a WBS provides the structure for cost allocation and scheduling.

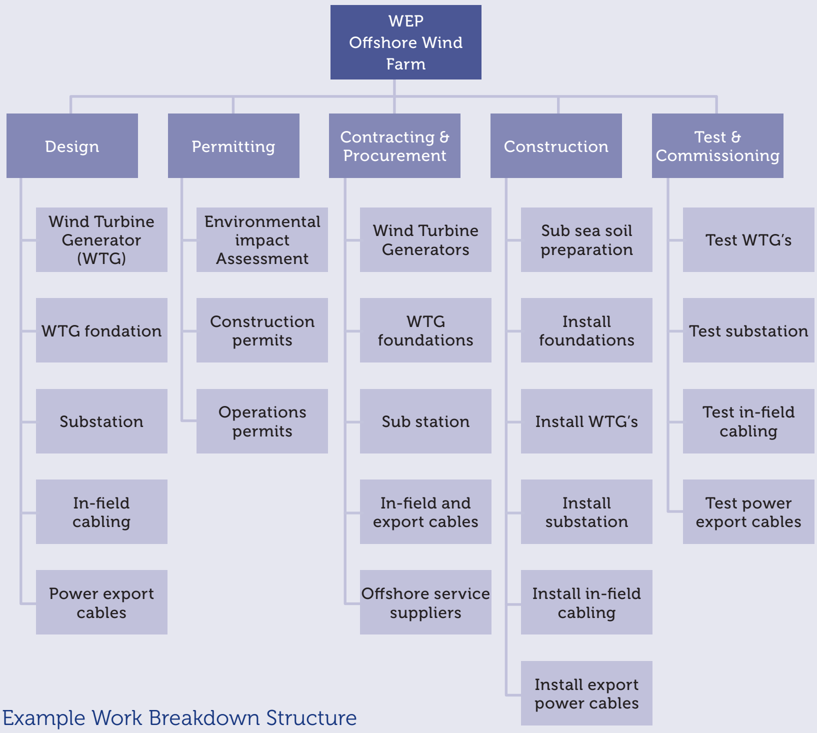


Figure 10.1: Example Work Breakdown Structure

In some industries a Product Breakdown Structure (PBS) instead of a WBS is being used. A PBS is based on products and defines the hierarchy of products and sub-products, rather than tasks and subtasks. In practice many combinations of WBSs and PBSs are used.

Once a WBS has been drawn up, a bottom-up estimate can be produced by costing the individual work packages at the lowest level and adding them up at the levels above. The result is a Cost Breakdown Structure (CBS). Similarly cost can be allocated top-down, starting at the top level of the WBS. In practice both ways are being applied, also depending on the purpose of the estimate and required accuracy. In Figure 10.1 an example of a WBS is shown for the design and construction of the offshore wind farm.

Next the main elements of a capital cost estimate are described, being a base estimate, allowances, contingency and escalation.

Base estimate

A base estimate, also called point estimate, is built up from the activities and deliverables identified in a Work Breakdown Structure (WBS). The more detailed the WBS becomes as the project matures, the more accurate the estimate becomes. The base estimate can be defined as an estimate including allowances, but excluding escalation, foreign currency exchange, contingency and management reserves (AACE, 2014).

The estimate consists of many different cost elements, depending on the scope of work and type of project. It includes all equipment, materials and labour required to execute the scope of work, also considering the execution approach and schedule. Cost elements to be considered can be split up in direct and indirect cost (Burke, 2003):

- Direct cost. These are costs that can be directly allocated to a specific scope of work or an activity. For example:
  - Equipment and material cost.
  - Cost of project management team.
  - Direct labour cost, like scaffolding, welders, fitters etc.
  - Direct expenses, such as 3rd party services or sub-contractor fees.
- Indirect cost or overhead cost. These are costs not directly attributable to the completion of an activity, which are typically allocated or spread across all activities on a predetermined basis (AACE, 2014). For example:
  - Field in-directs during construction, such as field administration, supervision, capital tools, start-up costs, etc.
  - Company overhead cost, like senior management, IT, human resource department, finance, etc.
  - Training cost, depreciation, insurance, taxes...etc.

The cost elements may be estimated using different estimating techniques depending on the level of scope definition and the size and complexity of the project.

Allowances

As part of the base estimate and on top of the base cost, allowances can be added to cover lack of scope detail or the 'known unknowns'. Below are some examples that are typically included in estimates as allowances:

- Design allowances for engineered equipment
- Material Take Off allowances, to cover differences between actual and calculated quantities
- Material inefficiencies, cutting and waste allowance
- Rework
- Non-productive construction time (poor productivity)
- Weather conditions

Contingency

Contingency is added to the cost estimate to cover the uncertainty and variability associated with a cost estimate, and unforeseeable elements of cost within the defined project scope (AACE, 2013). Contingency covers inadequacies in project scope definition, estimating methods and estimating data. The amount of contingency included in the estimate should be determined, as well as the method used to derive the appropriate amount.

Contingency is typically estimated using statistical analysis or judgment based on past asset or project experience. Contingency usually excludes:

- Major scope changes such as changes in end-product specification, capacities, building sizes, and location.
- Unforeseen major events such as earthquakes, labour strikes, etc. Management reserves (additional budget to be allocated at management's discretion).

The amount of contingency to add to the base estimate is usually related to the required confidence level of an estimate. Management can for example choose for a certain confidence level to fund a project. Most cost estimates have a P50 confidence level, which means that the amount of contingency added to the base estimate results in a 50/50 chance to either overrun or underrun budget.

In case a probabilistic risk analysis technique is applied to the base cost (see also Chapter 8), the probability of achieving a certain point estimate can be determined. A Monte Carlo simulation is the most commonly applied technique to analyse the impact of risks and uncertainties on project cost and schedule. The simulation not only calculates the probability of achieving a cost estimate, but it also calculates the associated required amount of contingency. It therefore uses a cost estimate without any contingency as a starting point for the simulation (AACE, 2011).

Normally only the high risks are used for the simulation. Each risk is quantified by determining its likelihood of occurring and potential cost impact. In more traditional approaches the impact of a risk on the estimate is represented by a three-point estimate, resulting in a triangular distribution as explained in Chapter 8.

According to Figure 10.2 there is a 30 % probability to achieve the base estimate (X). By adding contingency C1 to the base estimate, the confidence level of the estimate (Y) increases to 50 %, also called the P50 estimate. By adding even more contingency to the base estimate, for example C2, the confidence level increases to 80 %, also called a P80 estimate. Sometimes part of the contingency is allocated as a management reserve which is not freely available to the project team, but instead will be allocated by management.

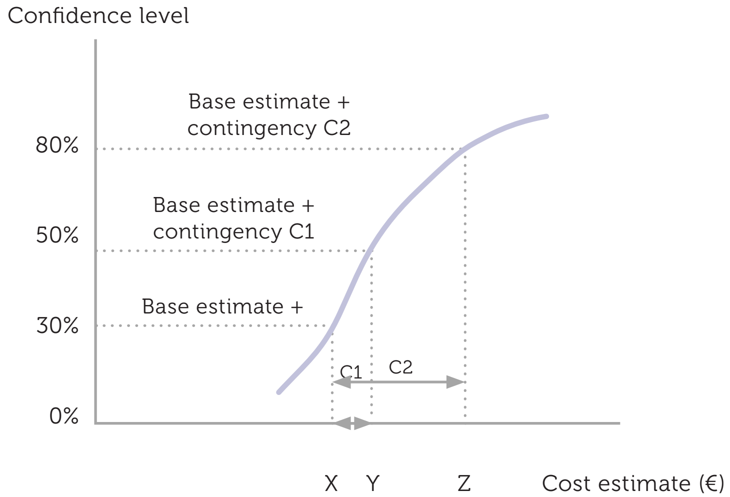


Figure 10.2: Estimate probability distribution curve

As contingency is related to uncertainties and risks, it is also possible to run down contingencies in case specific risks do not materialise during project execution. An example: the material selection for a gas treatment plant depends on the specific composition of the gas produced by new wells. This risk has been identified in the risk assessment and has been included in the overall contingency. After drilling the new wells it turns out that the gas composition allows for cheaper material to be applied. In that case the remaining contingency required till project completion can be lowered and associated budget can be freed up for other investments.

Escalation

Escalation is a provision in costs or prices for uncertain changes in technical, economic, and market conditions over time (AACE, 2014). It is important to consider this 'time value of money', since it can have an impact on purchasing power and earning potential. The two main components of escalation are inflation (or deflation) and market factors. Inflation is the rate at which the general level of prices for goods and services is rising over a certain period of time in an economy. It reflects the future value of money. Market factors reflect future market developments that, for example, can influence equipment and material prices.

Figure 10.3 shows the main components of a capital cost estimate.

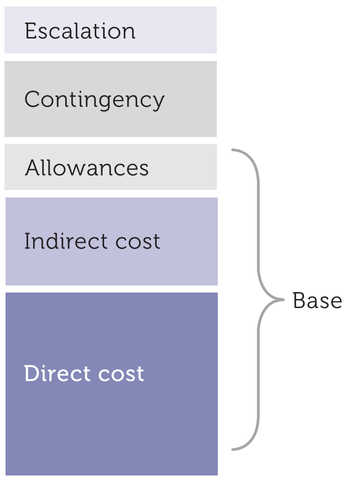


Figure 10.3: Capital cost estimate

The capital cost estimate as presented is also referred to as the Total Installed Cost, or Total Capital Investment. The capital estimate is an important input for the project economics as explained in Chapter 11.

Now that the estimate classes, structure and main elements have been defined, the most common cost estimating methodologies are described.

10.2.4 Cost estimating methodologies

Selecting the appropriate cost estimating methodology starts by determining the required level of accuracy of the estimate. This depends on the purpose of the estimate in a specific project phase and the available level of project definition. In this paragraph four common cost estimating methodologies are described. Depending on the available project definition these methodologies include a stochastic or deterministic approach (AACE, 2011).

Stochastic methods are often applied during the early project development phases, making use of estimating factors, metrics and models. For example, multiplying a (statistical) factor with equipment cost to calculate the total installed cost of a specific piece of equipment. It can be used for class 3 to 5 estimates, ranging from screening to budget estimates.

Deterministic methods are usually applied at a later stage when more scope detail is available (control or tender estimates). In practice it is possible to end up with a mix of these estimating methodologies in the same estimate, depending on the level of detail available for specific parts of the scope.

Four common estimating methodologies are briefly explained (Lester, 2014) (Burke, 2003).

Subjective

This methodology, sometimes called 'guestimating', is applied to provide a 'ballpark figure' at the early stages of a project. As there is no detailed information available yet, the accuracy of the estimate strongly depends on the estimator's experience of similar projects.

As an example the Lang Factor can be applied, being the ratio of the total cost of installation, or Total Installed Cost, to the cost of its major technical components. This factor is widely used in the process industry to help estimate the cost of new facilities. A typical Lang Factor for a new chemical unit would be in the range of 3.0 to 5.0. This means that the sum of all major equipment multiplied by a factor 3.0 to 5.0 gives a rough estimate of the total installed cost of the plant, including equipment, materials, construction and engineering.

Analogous

The analogous method, or comparative method, is using similar past projects to estimate the cost of a new project. It is applied when there is not sufficient data available to generate a detailed estimate yet, but sufficient technical definition to make adjustments of estimates made for similar projects. It is preferred to use quantifiable changes and apply factors to make the estimate adjustments, for example using scaling factors.

The Wind Farm

In the early phases of the wind farm project, an analogous or comparative cost estimate could be made, based on similar offshore wind farms that have been built around the world. Even local data could be obtained from the existing wind farm located next to the selected location of the project.
Although the technical complexity of wind farms seems to be relatively low, compared to for example chemical plants, there can be many differences between wind farm projects. To provide a proper analogous estimate, the following technical and execution aspects, amongst others, could be analyzed to make justifiable changes to estimates of similar projects:

- Seabed conditions and water depth (could lead to different soil preparation and subsea foundation)
- Weather conditions (impact of wind profile and sea state on design and construction time)
- Distance to nearest port
- WTG size and technical novelty
- Distance to onshore power grid
- Power cable routing (buried, drilling, crossing pipelines/cables, sensitive areas…etc)
- Local opposition against the project (could impact permitting duration)

Parametric

Parametric estimating, also called factoring or component ratio method, is a technique that develops cost estimates based upon the examination and validation of the relationships between a project's technical, programmatic, and cost characteristics as well as the resources consumed during its development, manufacture, maintenance, and/or modification (ISPA, 2008). These relationships are known as the Cost Estimating Relationships (CERs). Parametric models range from simple to very complex, depending on the number of CERs and the complexity of the algorithms used.
CERs can be based upon many different parameters like functional design parameters, quantities of equipment, hardware sizes and weight or operational environment, for example onshore versus offshore.

Analytical

The analytical method, also referred to as the detailed or engineering build-up method, is typically applied to generate the control estimate or a 'bid' estimate required by a contractor before submitting a bid. It is the most accurate, deterministic estimating method, and it requires the project to be broken down to the lowest WBS level. For each individual component the material and labour cost are then estimated and the sum of all pieces, including overhead, becomes the project estimate. The analytical method can be time-consuming and requires close cooperation between the cost estimator and the engineers who have developed all the details including the part lists, bill of material etc.

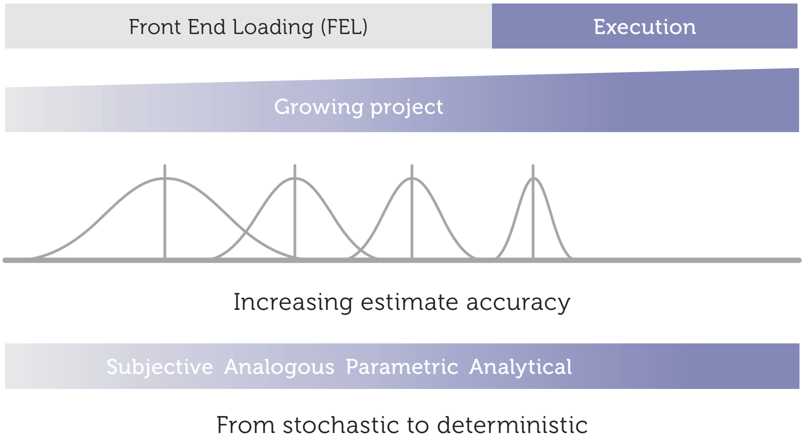


Figure 10.4: Estimate accuracy development

Figure 10.4 illustrates the development of the cost estimate accuracy and estimating method as the project matures from Front-End-Loading (FEL) to Execution. It also shows that the Subjective and Analogous methodologies are typically applied in the early project phases, while the Parametric and Analytical methodologies are used when there is a better project definition.

Human aspect

It is critical for an estimator to understand that estimating is not an activity to be performed in splendid isolation. Understanding the project scope and assuring all project team members provide the right input, requires a very proactive and open approach. There needs to be a two-way communication enabling the estimator to have a full understanding of the basis of estimate, while the other project team members develop an understanding of the impact that their specific scope or execution method has on the cost estimate. It should be an ongoing dialogue, starting early in the project development phase to avoid misalignment amongst stakeholders and unpleasant surprises when releasing the estimate. The discussed and agreed scope and execution assumptions need to be written down in a Basis of Estimate document.

It is also important to realise that stakeholders have different interests in the project and potentially will try to influence the cost estimate or the way it is presented. For example, a business manager is interested in submitting a competitive bid, aiming at winning a tender, so she will push for a lower estimate. A project manager wants to deliver his/her project within budget, so she will push for at least a realistic estimate, but perhaps even some additional pocket money. Similar pressure can be experienced when classifying specific cost. Some would like to classify training cost for operations as OPEX, while others would classify it as CAPEX. There are also examples of estimates being decreased to an acceptable level by management to obtain project sanctioning, resulting in a high chance of overrunning the approved budget.

10.3 | Planning and scheduling

10.3.1 Introduction

As already explained in Chapter 1, a project lifecycle exists of a number of distinct phases. In each project phase many activities are taking place and many deliverables are produced. To control the planning and execution of a project, all scope and activities need to be broken down into manageable activities, linked to a WBS as explained in the previous paragraph. The WBS forms the basis for compiling a schedule and brings scope, cost and schedule together. The WBS work packages can be broken down into lists of activities and events that form the basis for the project schedule. For each activity and event the predecessors, successors and the duration are defined and these interdependencies can be graphically displayed in a network planning. Next the network planning can be analysed to optimise the work sequence and project duration. Not all activities need to be scheduled at the same level of detail. It depends on the specific risk of an activity or work package and the level of control required.

There are many books written on how to create a network planning, explaining the different techniques in detail. The following part is only meant to give a high-level overview of the most common techniques, followed by an introduction into Gantt charts as a commonly applied method for schedule representation.

10.3.2 Network Planning

A network planning shows the logical sequence of project activities and the transfer points from one activity to another. There are two basic formats to draw a network:

- Activity-On-Arrow (AOA): activities are displayed as arrows and nodes represent the event or transition between the activities. Nowadays AOA is often referred to as Arrow Diagramming Method (ADM).

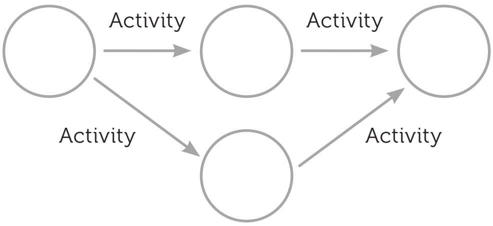


Figure 10.5: Activity-On-Arrow example

- Activity-On-Node (AON): activities are presented as nodes (rectangles or circles) and arrows are representing their relationships.

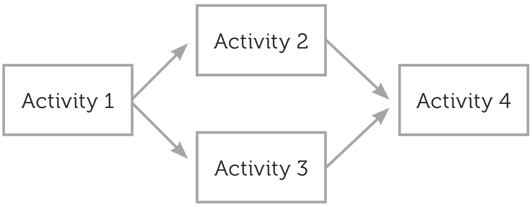


Figure 10.6: Activity-On-Node example

In general the AON format seems to be favoured over the AOA format, as it has some graphical advantages which make it easier to analyse and optimise the network.
There are two well-known network planning techniques, commonly used in projects:

- Program Evaluation and Review Technique (PERT)
- Critical Path Method (CPM)

Both techniques will be briefly explained.

Program Evaluation and Review Technique (PERT)
The PERT method was developed in the 1950s for the United States Navy. It was designed to analyse and represent the tasks involved in completing a project, using the AOA representation of activities and relationships. It is a probabilistic methodology aiming at determining the minimum time needed to complete the entire project.
The PERT method is usually applied on large-scale, non-routine projects, in conjunction with the Critical Path Method (CPM). PERT differs from the CPM, because it uses a probabilistic approach instead of adding up durations of critical activities to establish the critical path.
In the original PERT approach an estimate of the pessimistic (P), optimistic (O) and 'most likely' (M) duration is made for each activity. The expected duration of each activity is then calculated as a weighted average of these three durations (O + 4M + P)/6. The most likely duration is weighted four times as much as the other two values.

Critical Path Method (CPM)
CPM was developed around the same period as PERT and is commonly used in all kinds of projects to determine the critical path of a project and to assess float or slack in non-critical activities. It uses the AON representation of activities and relationships. The critical path consists of continuous successive activities that determine the minimum overall project duration. Float is the amount of time an activity may slip upon commencement and completion before becoming critical. By definition there is no float on a critical path, so any delay in the critical activities will directly impact the overall project duration accordingly. On complex projects there are often multiple (almost) critical paths running in parallel.
Nowadays the Precedence Diagram Method (PDM) is often applied to analyse the critical path, using the AON format to display the network planning. The PDM will be explained in more detail, using a simplified example of the wind farm case.

Precedence Diagram Method (PDM)
PDM, based on the Activity On Node (AON) method, shows activities as nodes and the relations between the activities as arrows connecting the nodes. The nodes can be displayed as boxes (Figure 10.7), including activity name, start and finish dates, duration and float.

<table>
<tr><td>ES</td><td>Duration</td><td>EF</td></tr>
<tr><td colspan="3">Activity</td></tr>
<tr><td>LS</td><td>Float</td><td>LF</td></tr>
</table>

Activity: Short description of activity (possible to refer to WBS)
Duration: Estimated time to complete the activity
ES: Earliest start
EF: Earliest Finish
LS: Latest Start
LF: Latest Finish
Float: LS - ES

Figure 10.7: AON node format for PDM

In projects it is common to have many complex relationships between the activities. There can be specific start and finish restrictions like:

- Finish to Start: this is the most straightforward restriction, dictating that an activity cannot start before its predecessor has been completed.
- Start to Start: an activity cannot start before its predecessor has started.
- Finish to Finish: an activity cannot be completed until its predecessor has been completed first.
- Start to Finish: an activity can only finish after the predecessor activity has started. So the predecessor must start first and then the successor can finish. This restriction does not appear very often, since there are usually easier ways to describe the relationship.

Usually there are also lead and lag times between activities. A start-to-start lag for example, determines the minimum amount of time that must pass between the start of an activity and the start of its successor.
Next PDM will be explained looking at a simplified example for the wind farm case.

The Wind Farm

In the table below some key activities of the wind farm project are listed, including their duration and predecessors. As explained in the table, there are some execution restrictions due to the limited availability of vessels. WTG testing can be performed in parallel with the WTG installation, starting 3 months after the start of WTG installation (a Start-Start relation, with a lag of 3 months).

Table 10.2: Network activities 'Wind Farm'

No.	Activity	Duration (months)	Predecessors	Comments
1	Soil investigation	3		
2	Wind study	3		
3	Design foundation	3	1	
4	Fabricate foundations	9	3	All foundations will be fabricated and delivered as one batch before start of installation
5	Soil preparation	12	3	
6	Install foundations	9	4, 5	Can only start after completing the soil preparation, due to vessel availability
7	Design WTG	6	2	WTG: Wind Turbine Generator

8	Fabricate and Test WTG's	15	7	
9	Install WTG's	9	6, 8	Can only start after installing all foundations, due to vessel availability
10	Test WTG's	7	9	Testing can start 3 months after starting the WTG installation (Start-Start, lag +3 months)

The following network can be drawn using the AON format and connecting all activities to their predecessors.

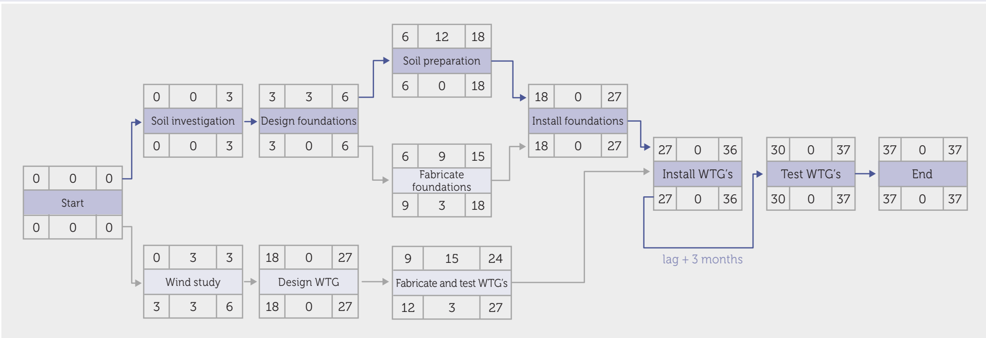


Figure 10.8: AON 'Wind Farm' network

A forward pass analysis will determine the early start and early finish of each activity. First determine the ES and EF for activities at the beginning of the network (Soil investigation and Wind study), next determine the ES and EF of the other activities following the network relations from left to right.
To determine the latest start and latest finish of each activity, a backward pass analysis has to be performed. The backward pass starts with determining the LS and LF of the last activity (Test WTG's) on the right, to then determine the LS and LF of all predecessors following the network relations from right to left.
From the analysis it becomes clear which chain of activities determines the overall duration, being the critical path (dark blue activities and blue arrows). In this case it takes 37 months to design and construct the Wind Farm.
For all activities the float can be calculated, being the difference between LS and ES.
For example 'Fabricate foundations' has a float of 3 months. So the fabrication could be delayed by 3 months and still finish on time to start the installation of the WTG's.

To complete the example, one simple change is made. After 5 months of soil preparation an additional vessel becomes available. The installation of the foundations could now start after 5 months of soil preparation instead of 12 months. Unfortunately the additional vessel cannot be used to install WTGs due to limited lifting capacity.

The Wind Farm

The only change made is the relation between 'Soil preparation' and 'Install foundations'. The relation has changed from a 'Finish to Start' to a 'Start to Start' relation with a lag of 5 months. All durations remain unchanged.
The updated network planning is shown below.

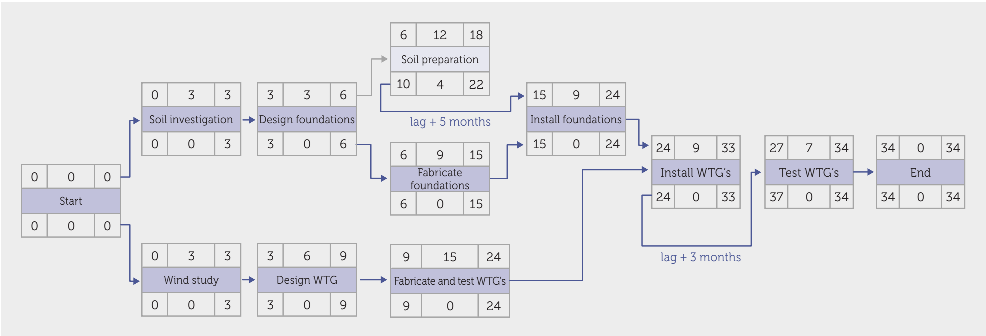


Figure 10.9: Updated AON 'Wind Farm' network

Now that the soil preparation is not on the critical path anymore, the overall project duration is reduced to 34 months. However almost all activities are critical now which probably indicates that the chance of meeting the 34 months is smaller as there is no float left in the schedule, except for the soil preparation. It would require a proper schedule risk analyses and cost/benefit analysis to decide if it is worth investing in the additional vessel.

As shown in the example, a simple adjustment can easily change the network analyses, resulting in a different critical path and overall duration.
Next a commonly used method to present a schedule is described, being the Gantt chart.

10.3.3 Gantt chart

The first bar chart was developed by a Polish engineer Karol Adamiecki in 1896. In the early 20th century Henry L. Gantt introduced the Gantt chart, a time-scaled bar chart, to the western world. It is a way to display the WBS and additional planning information in an easy-to-understand manner. Activities are represented by straight horizontal bars and, depending on their start and finish date, plotted against a calendar normally shown at the top. The relationships between the activities can be displayed as well.

ID	Task Name	Duration	Predecessors
1	**Wind Farm**	**740 days**	
2	Soil investigations	3 mons	
3	Wind study	3 mons	
4	Design foundation	3 mons	2
5	Fabricate foundations	9 mons	4
6	Soil preparation	12 mons	4
7	Install foundations	9 mons	5; 6
8	Design WTG	6 mons	3
9	Fabricate and test WTG's	5 mons	8
10	Install WTG's	9 mons	7; 9
11	Test WTG's	7 mons	10SS+3 mons

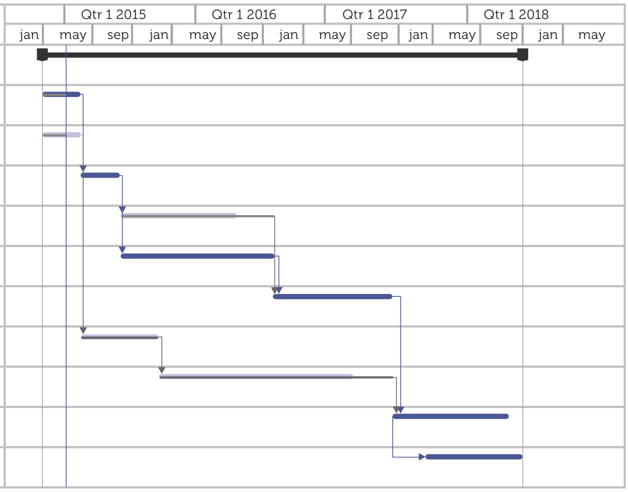


Figure 10.10: Gantt chart example Wind Farm

It is also possible to show progress per activity for example by colouring the baseline or drawing a progress bar underneath the activity bar. By combining all this information in an easy-to-read chart, management can have a good impression of the project at a glance.

Gantt charts can also be used to allocate resources to the activities. They can then be used to analyse and optimise resources and create a fully resource loaded schedule, showing all required disciplines and contractors over time. A common way to display resources over time is a histogram. In Figure 10.10 a Gantt chart example for the wind farm case is shown.

The figure represents all activities and their relationships by bars against a timeline on the top. The actual progress is shown as progress bars inside the activity bars and the critical path shows up in dark blue.
Nowadays most Gantt charts are generated automatically by planning or scheduling software like Microsoft Project or Primavera.

10.3.4 Probabilistic Scheduling

Similar to probabilistic cost estimating, probability distributions can be linked to the duration of scheduled activities, depending on the uncertainty of these durations.
Nowadays it is also possible to combine the probabilistic cost and schedule analysis in the same Monte Carlo simulation (see Chapter 8). It provides insight in the likelihood of meeting both project cost and schedule, by analysing the cost and schedule impact of the identified risks.

The analysis requires a detailed, resource loaded schedule, including all work to be completed and unbiased, most likely durations. The purpose of resource loading the schedule is to allocate the entire 'contingency-free' budget to the scheduled activities. Experience shows that schedules of 300 to 1000 activities can be used in the risk analysis. The number of risks is typically around 20 to 40.

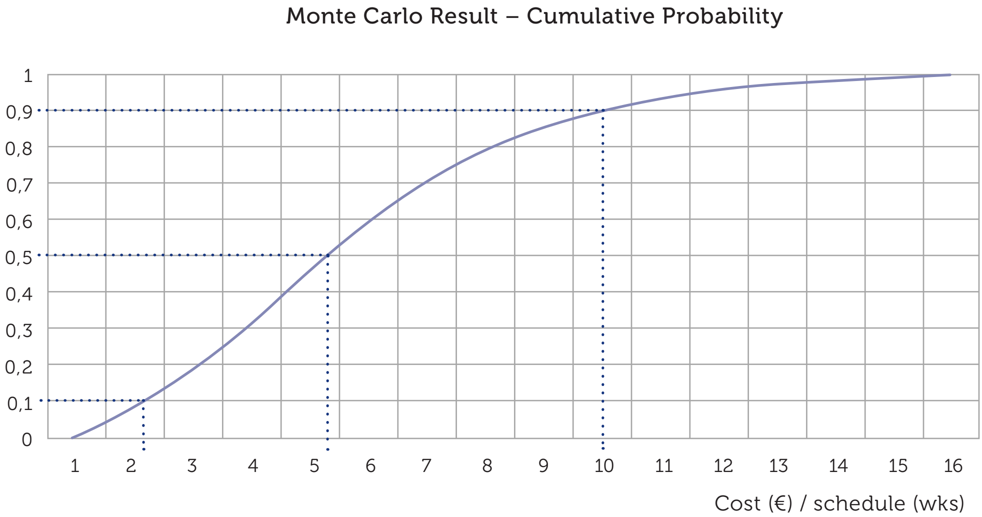


Figure 10.11: Cumulative probability curve

For each schedule risk the likelihood of occurring and the potential impact needs to be defined, similarly to the cost risk as explained in Paragraph 10.2.3.

Next a Monte Carlo simulation will generate a great number of iterations, combining many different cost and schedule impacts depending on their likelihood of occurring. This results in probability distribution curves for both cost and schedule as shown in Figure 10.11.

Human aspects
Similar to cost estimating, scheduling requires a proactive approach to ensure all relevant inputs are captured and that there is a good understanding of the execution assumptions and schedule risks. Often reference is made to the difference between a 'scheduler' and a 'planner'. A scheduler works in isolation and is very good at putting all activities in a scheduling software tool to develop a 'technically' sound schedule. A planner continuously interfaces with all relevant stakeholders to fully understand the phasing, priorities, execution approach, schedule risks and underlying assumptions.

Also schedules are being influenced by stakeholders depending on their specific drivers. Some stakeholders will have an interest to deliver the project as soon as possible, while a project manager would like to have a realistic schedule, taking into account specific schedule risks.

It is also not uncommon that some 'wishful thinking' creeps into the schedule during the early development phases. When the project scope is not well developed yet and not all related schedule risks are known, people tend to be too optimistic.

10.4 | Cost and schedule control

10.4.1 Introduction

A project needs to have appropriate controls in place to make sure it is completed against the agreed targets. Besides safety performance, risk management, quality and stakeholder satisfaction, these have been described in other chapters, the key aspects to control are cost and schedule.
Project control includes the following primary steps:

- Perform project planning, including establishing project cost and schedule baselines
- Measure project performance
- Compare measurements against the project plan and baselines
- Take corrective actions as may be determined through forecasting and further planning.

In essence it comes down to applying the well-known Deming circle; Plan, Do, Check, Act (PDCA-circle).

10.4.2 Project Controls Plan

It is common to write a 'project controls plan' in which the above steps are described in more detail. Depending on the size and complexity of a project, the project controls plan can also be included in the overall project execution plan. A project controls plan typically includes:

- Project controls organisation (organisation chart, roles and responsibilities)
- Project planning, key milestones
- Project scope and execution strategy
- Schedule development and resource planning
- Cost estimating and budgeting
- Risk management
- Cost control
- Progress and performance measurement
- Forecasting
- Change management
- Project reporting

Sometimes additional topics, like document control or auditing, can be included, depending on the tasks assigned to the project controls team.
It is also important to realise that there are possibly multiple contractors involved in the execution of the project, all performing their own project controls and reporting. Therefore large complex projects require an integrated project controls plan that clearly describes the interfaces with all contractors involved.
Another important aspect of project control is 'management of change'. A project requires a formal process to identify, assess and approve changes to the approved project plan and to capture the impact on schedule and cost.
Next the basis of schedule control, cost control and management of change will be explained.

10.4.3 Schedule control

The first step is to establish a baseline schedule. This is normally the schedule that, together with the project plan and baseline cost estimate, is authorised at project sanctioning. Although it is very well possible that more detailed execution schedules will be developed after sanctioning, schedule performance will be measured against the approved milestones.

The schedule is based on the WBS and progress will be monitored for the individual WBS elements. The level of schedule detail for each element and the WBS level at which progress is measured, depends on the complexity of the scope and schedule risks. For example applying a new technology which is on the critical path of your project requires more rigorous progress monitoring than a routine task with significant float.

To measure progress it is important to be able to measure real progress, or physical progress. Physical progress is the percentage of work scope completed at a certain date. It is determined by using predefined, objectively measurable achievements, like the number of completed engineering documents, or meters of pipeline installed. To determine the overall project progress, weighting can be applied to different WBS elements to reflect their relative contribution to the physical progress.

In a complex project there may be many parties involved in providing progress data. Contractors involved will normally monitor and report progress for their specific scope of work. The project planner must check and integrate all progress data to determine the overall project progress. The amount of involvement of the owner's planner also depends on the type of contracts. A lump sum turnkey contract requires less involvement from the owner than managing a reimbursable contract.

During project execution it can be decided to re-baseline the schedule if the original baseline schedule has become obsolete due to changes. If there are major changes of the project scope, or the actual progress deviates significantly from the original baseline schedule, it can be decided to establish a new baseline to measure progress. A need to re-baseline often results from poor project definition and/or poor project control. Reassessment of the project control process going forward is typically an element of re-baselining (AACE, 2014).

Besides monitoring progress and measuring schedule performance against the baseline, it is also common practice to forecast the remaining project duration.

10.4.4 Cost control

AACE International defines cost control as 'the application of procedures to monitor expenditures and performance against progress of projects or manufacturing operations; to measure variance from authorised budgets and allow effective action to be taken to achieve minimum costs' (AACE, 2014).
During the early project development phases, prior to formal project sanctioning, cost control basically comes down to managing all cost related to studies, design and engineering, owners team and other third party services. As soon as a final investment decision has been taken and there is an authorised budget to deliver the project, cost control becomes more advanced.

The first step is to establish a baseline estimate, usually being the authorised budget at project sanctioning. The cost performance will be measured against the initially authorised budget and any budget changes that were approved during project execution.

The level of detail at which cost control needs to be performed, depends on the specific scope of work and associated risk. Since the cost estimate is broken down according to the WBS elements, it can be decided for each element how to perform cost control and which supporting data to collect. For example a low risk WBS element being executed under a lump sum contract (see Chapter 9 for further explanation about contract types) requires less stringent cost control than high risk scope being executed on a reimbursable basis.

Since the same WBS activities and deliverables as included in the cost estimate are also in the schedule, the cost (CAPEX) phasing over time can be determined. The cost phasing can be visualised in a typical S-curve, also often used for cost control and reporting.

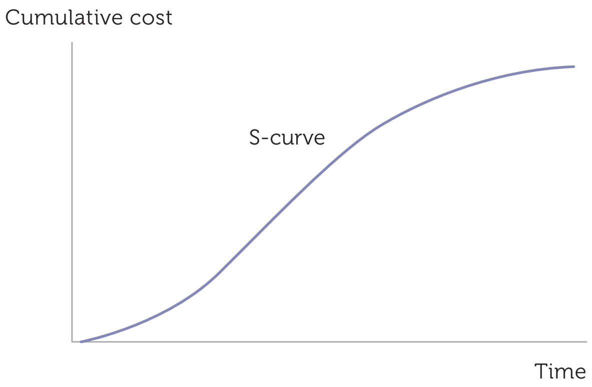


Figure 10.12: Cost S-curve

Besides an S-curve presenting cumulative cost over time, many different S-curves are used for project control and reporting. For example showing actual man hours, earned man hours, installed quantities or resources over time.
Next a commonly used integrated cost and schedule method will be described, the Earned Value Analysis.

Earned Value Analysis
Earned Value Analysis (EVA) is a quantitative method for evaluating project performance and predicting final project results, based on comparing the progress and budget of work packages to planned work and actual costs. The advantage of EVA is that both cost and schedule performance can be analysed using one method based on cost or monetary value.

To explain the EVA method some key terms need to be defined (Dierick & Van Biezen, 2009).

- The **Earned Value (EV)** of a work package, or the whole project, equals the sum of budgeted cost of the work performed to date. EV is also called the Budgeted Cost of Work Performed. So EV is not the same as the actual cost of work performed.

- The **Planned Value (PV)** equals the sum of budgeted cost of the work scheduled to date, also called Budgeted Cost of Work Scheduled.
- **Actual Cost (AC)** is the sum of all actual cost to date, also called Actual Cost of Work Performed.
- **Actual Time Spent (ATS)** is the total duration from start to date.
- **Budget At Completion (BAC**) equals the sum of all budgeted cost till the end of the project.
- **Time At Completion (TAC)** is the planned overall duration from start till end of the project.

The definitions above can be used to analyse cost and schedule performance in the following manner.
To analyse schedule performance the Schedule Variance (SV) or Schedule Performance Index (SPI) can be determined. Both measures indicate whether the project runs ahead or behind schedule.
- SV = EV – PV (positive number: ahead of schedule, negative number: behind schedule)
- SPI = EV/PV (number > 1: ahead of schedule, number < 1: behind schedule)

The cost performance can be analysed looking at the Cost Variance (CV) or Cost Performance Index (CPI). Both measures indicate whether the project runs over or under budget.
- CV = EV – AC (positive number: under budget, negative number: over budget)
- CPI = EV/AC (number > 1: under budget, number < 1: over budget)

Next the overall project duration and cost can be forecasted, taking into account the project performance to date.

The Estimated Time at Completion (ETAC) provides a forecast of the overall project duration, taking into account the schedule performance to date.
- ETAC = TAC/SPI (a SPI > 1: forecasted duration shorter than planned, SPI < 1: forecasted duration longer than planned)

From the ETAC the Estimate To Complete (ETC) can be derived, being the remaining forecasted time to complete the project.
- ETC = ETAC – Actual Time Spend (ATS)

The Estimated Cost at Completion (ECAC) gives a forecast of the total cost at completion of the project, taking into account the cost performance to date.
- ECAC = BAC/CPI (a CPI > 1: forecasted cost at completion under budget, CPI < 1: forecasted cost at completion over budget)

From the ECAC the CTC can be derived, being the remaining cost to complete the project.
- CTC = ECAC – Actual Cost (AC)

The importance of using Earned Value in the performance analysis will be illustrated by a simple example, in which the contribution of the activities to the overall progress is weighted equally.

EVA example

The table below shows the planning of 5 activities over 10 months, including the budgeted cost and planned spent per month for each activity.

Table 10.3: Activity planning and cost

	Time (months)				To date						
	Cost	1	2	3	4	5	6	7	8	9	10
Activity 1	€ 5.000	5k									
Activity 2	€ 10.000		10k								
Activity 3	€ 25.000			5k	20k						
Activity 4	€ 75.000			5k	10k	15k	25k	15k	5k		
Activity 5	€ 10.000									5k	5k

The cumulative cost curve is shown below.

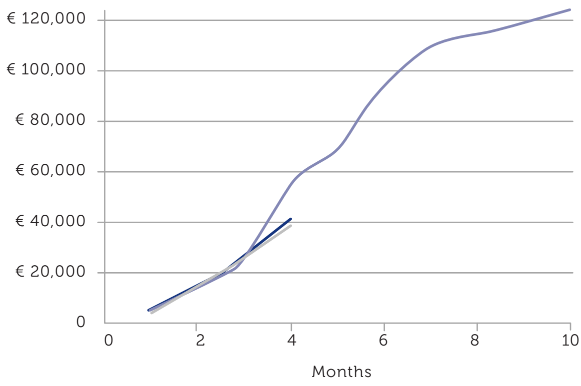


Figure 10.13: Cost curve EVA example

For each activity the EV is calculated, using the actual % complete. The table below shows the % complete, EV, PV and Actual Cost.

Table 10.4: EVA calculations

		% complete	EV	PV	AC
Activity 1	€ 5.000	100%	€ 5.000	€ 5.000	€ 4.000
Activity 2	€ 10.000	100%	€ 10.000	€ 10.000	€ 12.000
Activity 3	€ 25.000	75%	€ 18.750	€ 25.000	€ 15.000
Activity 4	€ 75.000	10%	€ 7.500	€ 15.000	€ 7.500
Activity 5	€ 10.000	0%	€ -	€ -	
	€ 125.000		€ 41.250	€ 55.000	€ 38.500

The project schedule and cost performance can now be calculated:
- *SV = 41,250 – 55,000 = -13,750 (running behind schedule!)*
- *SPI = 41,250 / 55,000 = 0.75*
- *CV = 41,250 – 38,500 = 2,750 (budget underrun)*
- *CPI = 41,250 / 38,500 = 1.07*

So although the project is running behind schedule, the cost performance looks positive. The schedule and cost forecast can also be calculated:
- *ETAC = 10 / 0.75 = 13.3 months*
- *ECAC = 125,000 / 1.07 = € 116,667*

Looking at the EVA analysis management might decide to take measures to reduce the schedule delay. Obviously this depends on the project's value drivers and possibilities to speed up the work. Adding more people to the job or introducing double shifts might be a solution, but will come at a cost.

10.4.5 Management of change

From the early phases onwards it is critical to manage project changes adequately to avoid scope creep, schedule delays and cost increases. Normally there is an approved project baseline against which changes are being assessed and formally approved before implementation. Some examples of changes are change of original business premises, additional safety or operational requirements, change of execution plan etc. Depending on the change there can be several disciplines, or even contractors, involved in assessing the impact of the change.
For most projects it is common to have a formal change management process to identify, assess and approve changes to the project plan and to capture the impact on schedule and cost. Depending on the impact of a change, project management or a more senior level approves the implementation of the change.
To assess the cost impact, it is important to differentiate between changes due to already identified uncertainties and unexpected scope changes. The first category is likely already included in the contingency and therefore does not require additional budget. If the change concerns unforeseen additional scope, the budget needs to be raised.

Human aspect

Similar to the previous paragraphs on the human aspect, there are many stakeholders with different interests when it comes to controlling a project. Just a few examples to illustrate situations that have occurred in practice:
- Management decreasing the baseline cost estimate to have a project sanctioned.
- A construction contractor reporting more construction progress than is actually made to meet a project milestone and receive an incentive fee.
- A project manager forecasting the overall project cost too optimistically to positively influence his appraisal.
- An engineering contractor not making any effort to improve the engineering efficiency, aiming to maximise the engineering man hours under a reimbursable contract.

It requires an experienced project team to recognise these different interests, and challenge the data received for cost and schedule control.
Another known issue is the fact that most people are too optimistic about project execution and resolving problems along the way. This often results in significant 'wishful thinking' when forecasting project duration or the overall project cost. It takes experience to recognise these situations and avoid over-optimistic estimates and schedules.
Management of change requires discipline from the project team and other parties involved. All parties involved need to follow the formal change management process and all relevant disciplines need to assess the impact of the change. It happens in practice that, due to time pressure, changes do not follow the formal change process, which can lead to unsafe situations or unpleasant schedule or cost surprises later on. A common reason not to follow the change management process is simply because it is taking too long. Especially during construction there is not much time to wait for the formal approval of a change before implementation. Therefore it is key to structure the process such that the turnaround time is as short as possible, and at least the relevant disciplines have reviewed a change prior to formal approval.

10.5 | Progress reporting

In practice there are many different reports for many different purposes and audiences. Some examples are listed below:

- Weekly internal project highlights
- Monthly progress reports
- Project portfolio updates
- External progress reports for investors and partners
- Management dashboards

Various stakeholders need to be informed and might ask for different information. Depending on their interest and management level, the specific information, aggregation level and reporting frequency can vary. It also depends on the project development phase, because progress reporting can become much more complex as the number of external parties increases towards execution.

Many project teams consider progress reporting as a burden that not necessarily adds any value to the project. Especially the sometimes many ad hoc requests for information or progress data are disrupting the day-to-day project activities. Besides disruption, this ad hoc reporting can easily lead to mistakes or the provision of incomplete information. On top of that this information could start to 'live its own life', being used and presented by stakeholders in their own interest.
The trick is to produce one simple, formal progress report that satisfies most of the stakeholders. However there can still be good reasons to compile tailor-made reports, but always using the same data as included in the formal progress report. Ad hoc requests should be minimised to limit the additional reporting burden of the project team at any time.

The positive thing about reporting is that it requires the project team and third parties to frequently review project performance and to update the cost and schedule forecasts. It forces communication between all parties to first collect the required progress data and next to explain project performance and required recovery measures to the various stakeholders.

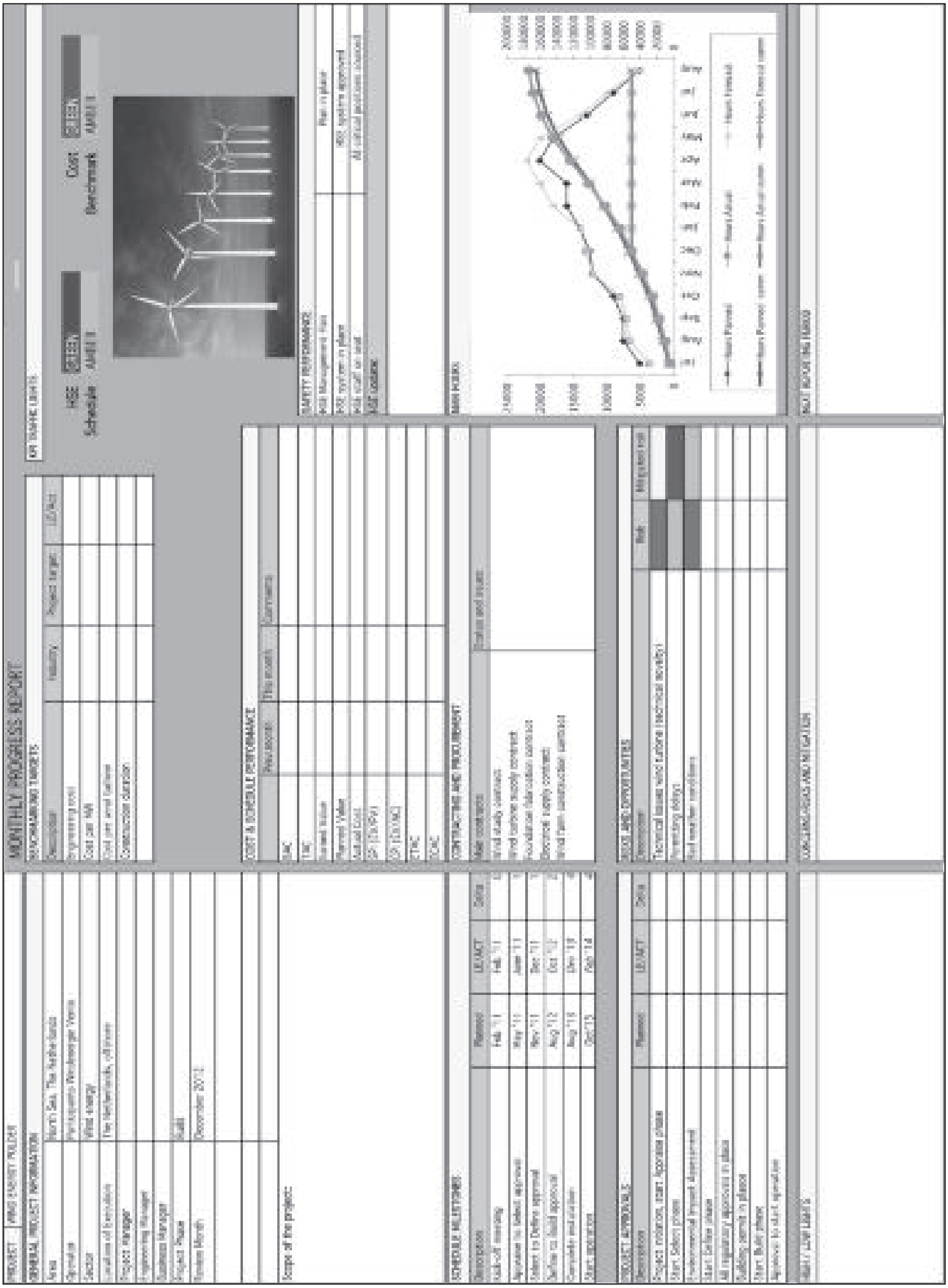


Figure 10.14: Example of a progress report of the Wind Farm Energy Polder

Progress reports can also have a contractual purpose, for example to formally document approved scope changes or to document the status of earned incentives. The reports could even end up in court, in case a claim needs to be settled after project completion.
The data and information in the progress report needs to be highly reliable as the project team and other stakeholders must be able to take decisions based on this report. Example: A project manager decided to introduce working shifts to catch up, following a progress report that showed a poor construction progress. Two months later it turned out that there was a significant delay in collecting and reporting construction progress data and that the actual
Construction progress was even ahead of schedule. Accurate progress reporting could have prevented the additional cost of working shifts.
A progress report typically includes the following topics:

- Management summary
- HSE performance
- Project Key Performance Indicators (KPIs)
- Key risks and mitigation actions
- Schedule
- Cost control
- Quality
- Engineering
- Contracting and Procurement
- Construction
- Commissioning and Start-up
- Scope changes

For schedule and cost most reports include progress and cost curves, showing the planned, actual and forecasted data. An example of a typical monthly progress report for the Wind Farm project is given in Figure 10.14.

Human aspect

The quality of a progress report strongly depends on the competencies of the project controls team and their understanding of the scope and execution. The team must be able to challenge the received data and information and should understand how to integrate it into one overall progress report. The project manager should take full ownership of the progress report, being able to explain all information included.
For the project controls team it is important to realise that informal communication can be as important as formal communication. For example a cost controller who really connects with the project team, who understands the scope of work and knows what is going on during construction, can fulfil his role much more proactively than a cost controller sitting behind his desk all day.

The way progress is being presented and communicated can be influenced by many parties. A project manager can benefit from presenting a success story, while a contractor would like to report all mistakes and omissions from the owner. It is therefore important to ensure the report reflects the actual situation and represents issues in a fair way. In the end it comes down to trust between all parties involved, particularly between the owner and contractors. Since conflicting interests will exist at all times, making money versus saving money, it works best to openly acknowledge these differences and to focus on the common interests and goals, like for example a good safety performance.

10.6 | Project controls team

The Project Controls (PC) team is part of the overall project team and can typically include the following disciplines:

- Cost estimation
- Scheduling
- Cost control
- Risk management
- Document control

The PC team is normally led by a Project Controls lead or manager and the size of the team will vary depending on the size and complexity of the project. The PC manager is normally a member of the project management team.

The PC team plays a vital role in providing management information to the project team and various stakeholders. To fulfil this role the PC team needs to:

- Establish a clear project baseline, including a proper understanding of the business drivers.
- Compile a fit-for-purpose project controls plan.
- Proactively collect and challenge project information and data.
- Integrate and analyse the information from all sub-projects, disciplines and third parties.
- Provide reliable management information to the project team to help them take the right decisions.
- Consolidate all relevant progress information and data in a formal progress report.
- Support management of change and assess the impact of changes on cost and schedule.
- Facilitate risk management.

The PC team can only succeed if they are involved from the start of the project, if they are being recognised for their critical role and provided they communicate and engage with the right people at the right time. This requires full support from project management and the right mix of analytical and people skills in the PC team.

10.7 | Fit-for-purpose project controls

Fit-for-purpose project controls means applying the right level of cost and schedule control for a project in each lifecycle phase. For large projects this can even be different for each major WBS element. The level of control depends on the scope of work, associated risk, complexity and also the contracting strategy. Building a multi-billion euro chemical plant under a joint venture with a consortium of contractors requires a different level of control than building a small-size pedestrian bridge by one contractor under a lump sum contract.

Below some examples are given to illustrate the need for fit-for-purpose project controls.

Cost estimate

Depending on the project phase and the level of project definition, the completeness and accuracy of the estimates varies. Sometimes stakeholders are asking for a very accurate estimate in the early development phases of a project, while the required level of project definition is not available yet. This can result in an extensive exercise and expenditure, to obtain the necessary detail required to establish the desired level of accuracy. The issue with producing very accurate estimates too early, lies in making too many assumptions and trying to collect reliable cost data while there are still a lot of unknowns and uncertainties. A famous one-liner applies here: ‘It is better to be roughly right, than precisely wrong.’ So unless there is a clear need for an accurate (deterministic) estimate early in the development, likely related to risk, stakeholders should really focus on the objective of an estimate and on which decisions it should support.

Schedule

Same as for the cost estimate it is important to make sure that the level of scheduling detail is aligned with the purpose of the schedule. It is no use to develop a detailed, fully resource loaded schedule, if you only need rough milestones and lead times to compare different design concepts in the early project phases.

Similarly it is highly unlikely that the small-size pedestrian bridge requires a fully integrated cost and schedule Monte Carlo risk analysis. On the flip side, the multi-billion chemical plant does require this integrated analysis since the complexity and associated risks are entirely different.
In summary, applying fit-for-purpose project controls requires full understanding of the project value drivers, risks and the specific purpose of estimates and schedules in each project lifecycle phase.