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PROJECT MONITORING AND CONTROL

Voorwoord van de redactie
Dit artikel is het eerste van een drieluik over project monitoring en control dat in opeenvolgende edities van COSTandVALUE wordt gepubliceerd. De onderwerpen zijn achtereenvolgens 'Planning en scheduling', 'Cost Estimating' en 'Cost and Schedule control'. De artikelen zijn gebaseerd op het recentelijk verschenen boek 'Management of Engineering Projects – People are Key' (Bakker & De Kleijn, 2014) waarin een fit-for-purpose project management aanpak en de mensen in het project team centraal staan.

1. Introduction

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' (Oxford, 2014). This is the essence of controlling a project, being able to influence the course of a project by knowing where to go, knowing where you are now and knowing how to get to your final destination.

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 overspent the budget (or sometimes underspent!)
- It took months before we produced at design capacity after start-up
- The operational cost turned out to be much higher than predicted

Realizing 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 pro-ject 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 hand-over to the end-user, project controls matures with it. As the level of project definition grows over time, project controls will be performed on a more detailed level.

One of the key elements of project controls is scheduling. It is important to realize that scheduling requires a pro-active approach to ensure all relevant inputs are captured and 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. As extreme examples of this you can come across a 'scheduler' who has never visited the construction site, or run into a 'planner' who knows more about construction than the construction manager!

Samenvatting

Het artikel in deze editie gaat over project planning. Na een korte introductie van Project Controls in het algemeen wordt uitgelegd hoe een planning kan worden opgebouwd, varierend van een eenvoudige netwerkplanning tot een meer geavanceerd 'probabilistic schedule'. Evenals in het oorspronkelijke boek worden ter verduidelijking eenvoudige voorbeelden aangehaald van een fictief offshore windmolenpark project. Tevens wordt met behulp van praktijksituaties geillustreerd dat het toepassen van de theorie in de praktijk niet altijd eenvoudig is. Afsluitend wordt kort ingegaan op het fit-for-purpose plannen van een project. Dit komt neer op het afstemmen van de structuur en het detailniveau van een planning op het doel van de planning.

The next paragraphs explain the basic steps and commonly applied techniques to develop a project schedule. At the end of the article a short reflection on a fit-for-purpose approach is given.

2. Planning and scheduling

It is common practices that large projects follow a number of distinct phases with formal reviews, or gates, in between at which the decision is taken to continue into the next phase or not. Like most 'engineering' projects, it usually starts with the development of a business case. Based on a rough project scope, high level schedule and rough order of magnitude cost, the project economics are being determined, often for business planning purposes, or early assessment of the feasibility. As the project matures, the most promising development concept is being selected and more detailed information becomes available as engineering progresses. This more detailed information is also translated into a more detailed schedule and cost estimate.

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 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 2.1 - 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 there are many combinations of WBS's and PBS's being used.

Figure 2.1 shows an example of a WBS for the design and construction of an offshore wind farm.

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 analyzed to optimize the work sequence and project duration.

Not all activities have to be scheduled at the same level of detail. It depends on the project phase, the specific risk of an activity or work package and the required level of control. For example during construction the schedule requires much more detail than during early business development. And even within the construction phase there can be difficulties changing the structure and details of a schedule when moving from construction into commissioning and start-up. Typically construction schedules are structured around physical construction areas, while commissioning and start-up are normally based on operational hand-over systems.

There are many books written on how to create a network planning, explaining the different techniques in detail. The following paragraph 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.

2.1 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).

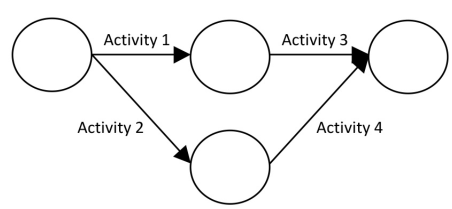


Figure 2.1.1 - Activity-On-Arrow example

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

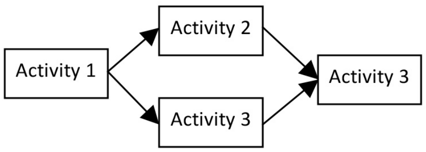
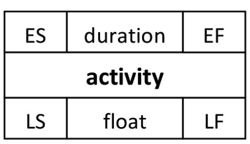


Figure 2.1.2: Activity-On-Node example

In general the AON format seems to be favored over the AOA format, as it has some graphical advantages which make it easier to analyze and optimize the network.
There are two well-known network planning techniques, commonly used on projects:
- Program Evaluation and Review Technique (PERT)
- Critical Path Method (CPM)

Both techniques will be explained in short.



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 2.1.3 - AON node format for PDM

Program Evaluation and Review Technique (PERT)
The PERT method was developed in the 1950s for the United States Navy. It was designed to analyze 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 by 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 that an activity may slip in its start 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 that require close monitoring.

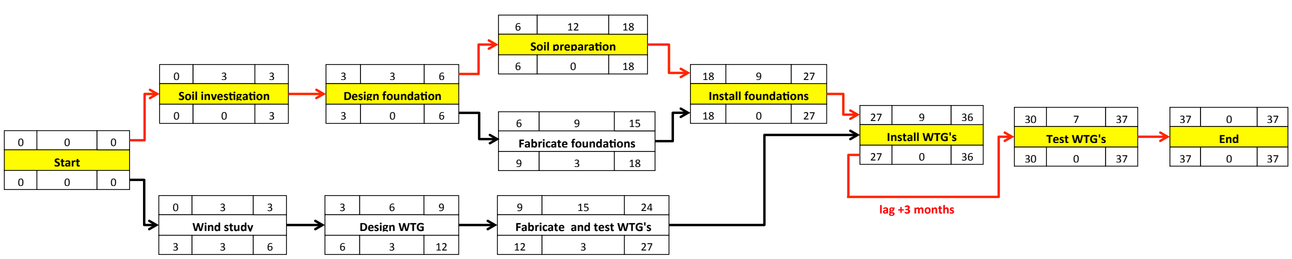


Figure 2.1.4 - Network planning example

Nowadays the Precedence Diagram Method (PDM) is often applied to analyze the critical path, using the AON format to display the network planning.

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 2.1.3), including activity name, start and finish dates, duration and float.

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 straight forward 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.

In fig. 2.1.4 a simplified network planning for the offshore wind farm case is given, using the AON format.

In the network above the key activities of the wind farm project are shown, including their relationships. The critical path is marked by the red arrows connecting the yellow critical activities and shows an overall project duration of 37 months. The other activities are not critical as they do not determine the overall project duration. For example 'Design WTG' has a float of 3 months, meaning that the activity may slip by 3 months before it becomes critical and has an impact on the overall project duration. Just imagine the complexity of a network planning in real life, adding many more activities and interfaces.

Next a commonly used method to present a schedule is described, being the Gantt chart.

2.2 Gantt chart

The first bar chart was developed by a Polish engineer Karol Adamiecki in 1896. At the beginning of the 20th century Henry L. Gantt introduced the Gantt chart, a time-scaled bar chart, in 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.

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

Gantt charts can also be used to allocate resources to the activities. It can then be used to analyse and optimize 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 2.2.1 a Gantt chart example for the wind farm case is shown.

In fig. 2.2.1 all activities and their relationships are represented 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 red.

Nowadays most Gantt charts are generated automatically by planning or scheduling software like Microsoft Project or Primavera.

2.3 Probabilistic Scheduling

The last commonly applied scheduling method to be discussed is probabilistic scheduling. Probability distributions, like a simple triangular distribution, can be linked to the duration of scheduled activities, depending on the uncertainty of these durations. The analysis requires a detailed, resource loaded schedule, including all work to be completed and unbiased, most likely durations. Experience shows that schedules of

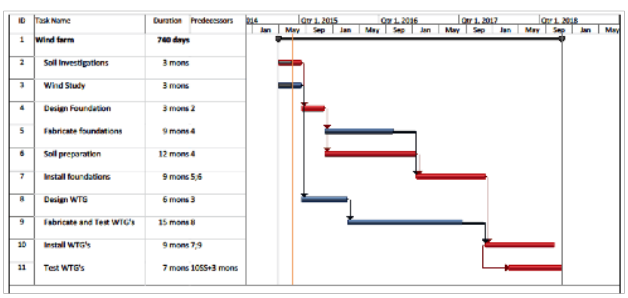


Figure 2.2.1 - Gantt chart example wind farm

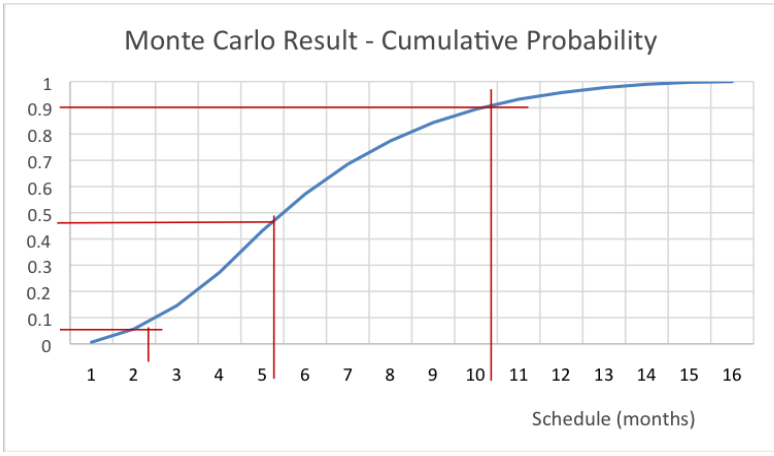


Figure 2.3.1 - Cumulative probability curve

300 to 1000 activities can be used in the risk analysis.

In practice the risk assessment includes a mix of uncertainty ranges of individual activities and discrete risks impacting specific activities. The number of discrete risks is typically around 20 to 40. For each schedule risk the likelihood of occurring and the potential impact needs to be defined.

Subsequently a Monte Carlo simulation will generate a great number of iterations, combining many schedule impacts depending on their likelihood of occurring. This results in a probability distribution around the schedule that can be presented as a cumulative probability curve shown in figure 2.3.1. What is typically derived from the simulation results is a P10, P50 and P90 schedule, representing schedules that have 10%, 50% or 90% probability of success.

Most important for a good quality probabilistic schedule, is the quality of the input. Besides a good schedule, this requires a realistic assessment of schedule risks. Typically these risks are being assessed with involvement of all critical parties and engineering disciplines working on the project, who of course have their own bias. Depending on project history or peoples personal project experiences, their assessment of risks can be too pessimistic or overly optimistic. The challenge is to have a balanced assessment of the risks to estimate the impact of threats and opportunities as realistic as possible.

Also do not forget the non-technical risks, as the impact of these risks on projects has become more significant over the past decennia. Non-technical risks are sometimes hard to assess, while the impact on the schedule can be huge. For example, dealing with public opposition while obtaining the required environmental permits for a project.

3 Fit-for-purpose approach

Fit for purpose scheduling means developing a schedule with the right structure and level of detail, depending on the project phase, risks and 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 a small size project for a pedestrian bridge requires a full Monte Carlo schedule risk analysis. On the flip side, a multi-billion chemical plant does require this advanced analysis since the complexity and associated risks are completely different.

So again the level of schedule details and as such the effort to put into a project schedule should be tailored around the purpose of the schedule and schedule risks.

And finally be aware that schedules will be influenced by multiple stakeholders depending on their specific interests. A well known example is the potential difference of interest between a business development manager and a project manager. While the business development manager wants to present his business case on paper as optimistic as possible to pass the investment hurdle, the project manager would like to have enough time to realistically finish the project. Also consider the interests of contractors involved, joint venture partners, or even governments who have made promises to their voters.

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