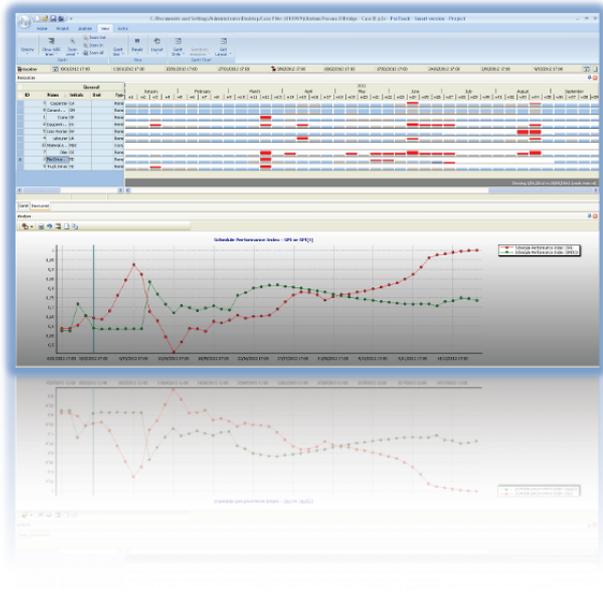
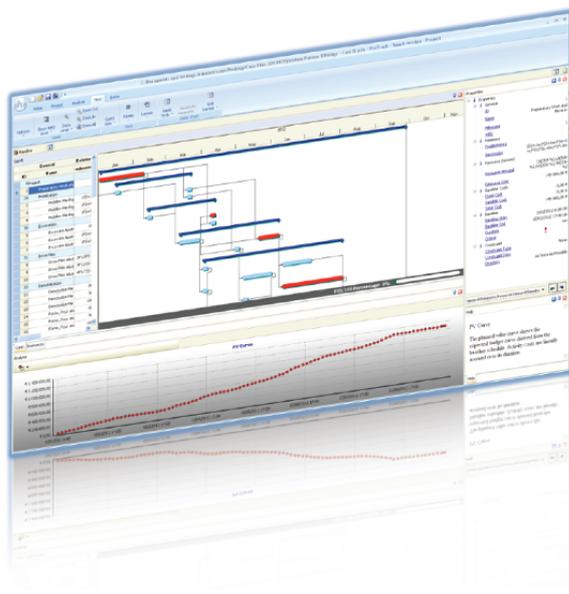


Dynamic Scheduling on your Desktop

(using ProTrack 2.0 developed by OR-AS)



Mario Vanhoucke and Tom Van Acker

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Chapter 1 Preface

1 Dynamic scheduling

1.1 The schedule, risk and control triangle

Project baseline scheduling, risk analysis and project control are crucial steps in the life of a project. The project manager uses the project schedule to help planning, executing and controlling project activities and to track and monitor the progress of the project. A major component of a project schedule is a work breakdown structure (WBS). However, the basic critical path method (CPM) schedules, or its often more sophisticated extensions, are nothing more but just the starting point for schedule management. Information about the sensitivity of the various parts of the schedule, quantified in schedule risk numbers or of a more qualitative nature, offers an extra opportunity to increase the accuracy of the schedules and might serve as an additional tool to improve project monitoring and tracking. Consequently, project scheduling and monitoring/control tools and techniques should give project managers access to real-time data including activity sensitivity, project completion percentages, actuals and forecasts on time and cost in order to gain a better understanding of the overall project performance and to be able to make faster and more effective corrective decisions. All this requires understandable project performance dashboards that visualize important key project metrics that quickly reveal information on time and cost deviations at the project level or the activity level. During monitoring and tracking, the project manager should use all this information and should set thresholds on the project level or on lower WBS levels to receive warning signals during project execution. These thresholds serve as triggers to take, when exceeded, corrective actions.

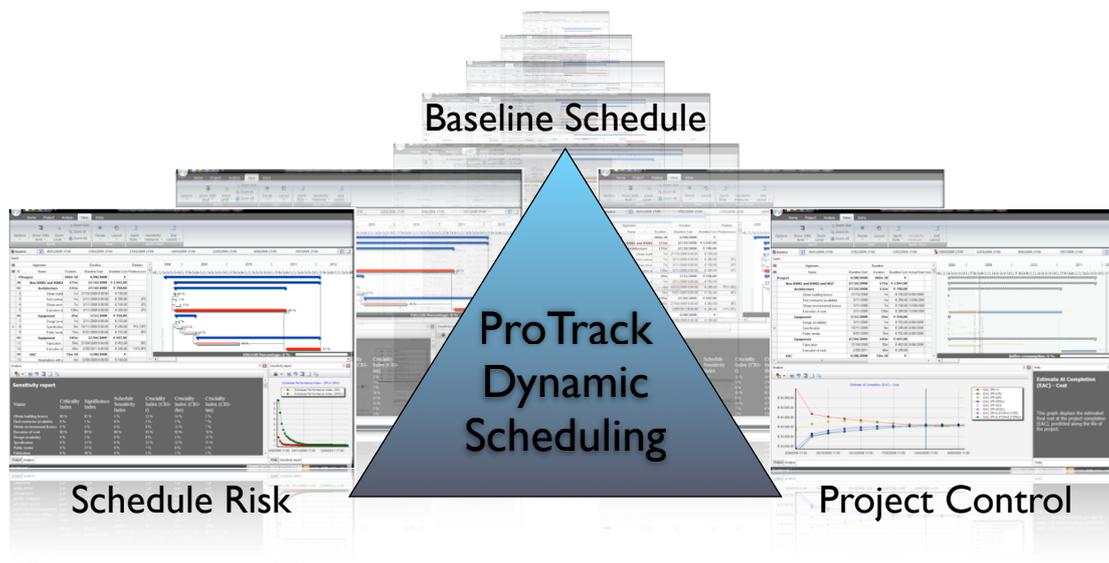


Figure 1.1. Dynamic scheduling: the schedule, risk and control triangle

1.2 ProTrack

ProTrack is a standard project scheduling tool which enables the user to create a baseline schedule from activity information of a project, guides the user in the schedule risk analysis and facilitates the project tracking and monitoring process using established as well as novel EVM methods. This triangular role of a

project schedule is often labeled as “dynamic scheduling” (see figure 1.1) to highlight the need and ability of project scheduling software to dynamically create a baseline schedule environment that provides dynamic information during the project execution and that can be easily adapted using the new information during project monitoring and tracking. Consequently, the purpose of ProTrack’s project scheduling engine is threefold:

- **Baseline schedule construction:** A project baseline schedule visualized in a Gantt chart acts as a point of reference in the project life cycle. It should especially be considered as nothing more than a predictive model that can be used for resource efficiency calculations, time and cost risk analysis, project tracking and performance measurement, and so on.
- **Schedule risk analysis:** When management has a certain feeling of the relative sensitivity of the various project activities on the project objective, a better management’s focus and a more accurate response during project tracking should positively contribute to the overall performance of the project.
- **Project tracking/monitoring:** Using dynamic information during project progress to improve corrective action decisions is the key target of project tracking and monitoring. The dynamic performance information obtained through EVM will be dynamically used to steer the corrective action decision making process and improve the overall success of the project.

2 More information

ProTrack 2.0 is also used in various research projects at Ghent University and a growing number of international universities. More information on the research and the upcoming developments of OR-AS will be briefly described in the section below. More information can be found at www.or-as.be or www.protrack.be.

2.1 Research

The previous version, ProTrack 1.0, has been developed as the result of a research project that has been awarded by the Project Management Institute Belgium and the International Project Management Association. Most research done before and during the development of ProTrack can be situated in the so-called Project Life Cycle (PLC, see figure 1.2). This cycle defines all phases between the initial start en final end of the life of a project, and has been extensively described in various sources.

The aim of the research was threefold. First, the research aim was to search to determinant factors that influence the accuracy of earned value based predictive methods to forecast a project’s final duration. A distinction is made between static determinants, which can be calculated before the start of the project (i.e. during definition and scheduling phase, see study 1 of the figure 1.2) and dynamic determinants, which can be calculated during the project’s execution and control phase (see study 2). Obviously, the ultimate goal is not the accuracy for the sake of the accuracy, but rather to use this static and dynamic information to guide and improve the corrective action decision making process (see study 3).

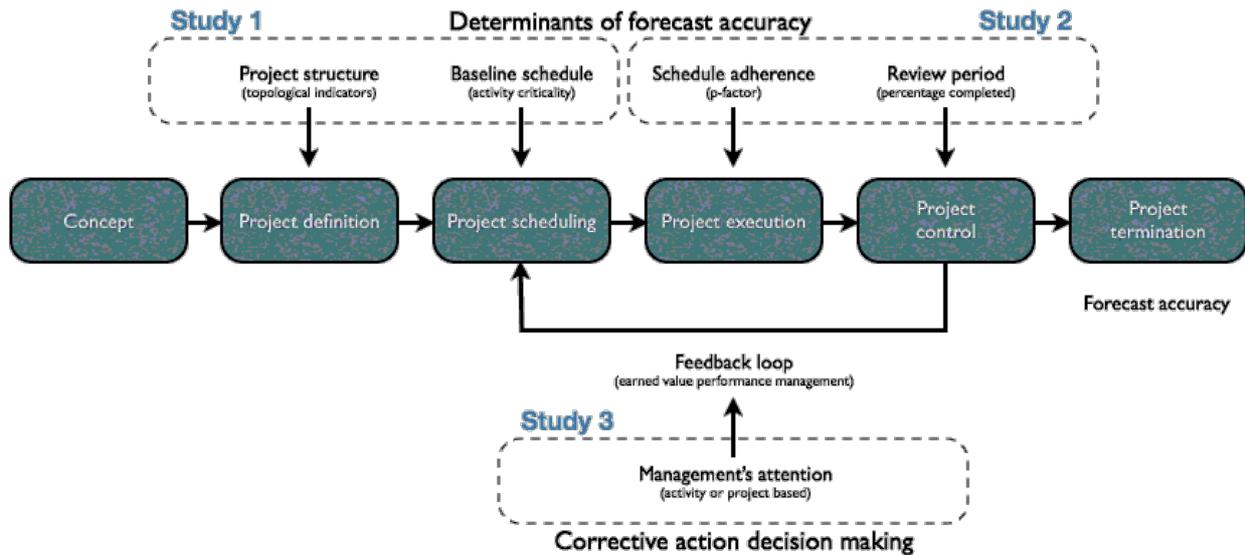


Figure 1.2. The project life cycle and the three integrative studies for the development of ProTrack

This research has led to several publications published in peer-reviewed journals and more popular journals, and an award winning book “Measuring Time: Improving Project Performance using Earned Value Management”. For more information, see the list of references below or contact our research section on www.protrack.be.



More background information can be found in the book “Measuring Time - Improving project performance using Earned Value Management”. Read chapters 1 to 3 for the EVM tracking period calculations and chapter 4 for the forecast accuracy study. Visit www.or-as.be/measuringtime for information about the availability of the book. The book has been awarded by PMI Belgium (2007) and IPMA in 2008.

2.2 Upcoming

2.2.1 Project Management Knowledge Center

In order to share our experience with researchers, students and practitioners, a Project Management Knowledge Center will be set up with articles, videos, recent news on project management and much more. Expected release of the www.pmknowledgecenter.com webpage is in the fall of 2011.

2.2.2 iphone app

In order to bring the principles of EVM to a broader audience, an iphone app has been developed which allows the user to automatically generate project data under a strict user defined design. Its main features

are borrowed from ProTrack and are adapted to serve as an EVM learning tool. Available soon on www.protrack.be.

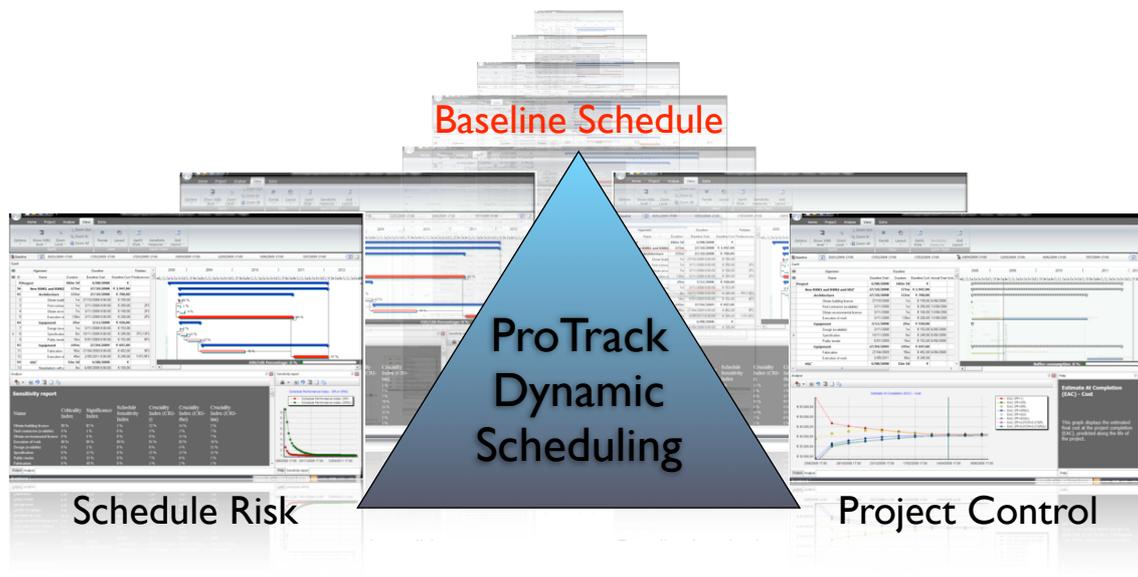
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Last update: November 2010

Chapter 2 Baseline Scheduling with ProTrack



The construction of a project baseline schedule is often a time-consuming and cumbersome task. However, the central role of the baseline schedule in a Schedule Risk analysis and in the Project Control phase cannot be underestimated. It should indeed be generally accepted that the usability of a project schedule is to act as a point of reference in the project life cycle, and hence, a project schedule should especially be considered as nothing more than a predictive model that can be used for resource efficiency calculations, time and cost risk analyses, project tracking and performance measurement, and so on.

ProTrack's Standard Version contains most of the basic baseline scheduling options discussed in this chapter. The more advanced ProTrack versions (Sensitivity Scan, Time Shuttle and Smart Version) make the connection between Baseline Scheduling, Schedule Risk and Project Control.

1 Project data

1.1 Project generation

Generating a project file can be done in four ways:

- Open a recent project that you saved during a previous ProTrack session.
- Start from scratch and build your own input project file.
- Generate a project file from the Random Network Generator (RanGen).
- Import a file from MS Project.

1.1.1 Build your own project

A project requires some data that need to be manually entered in the Gantt chart data grid of ProTrack, as will be discussed in section 1.3. Obviously, any project can be saved and reopened at a later ProTrack session, as shown in figure 2.1.

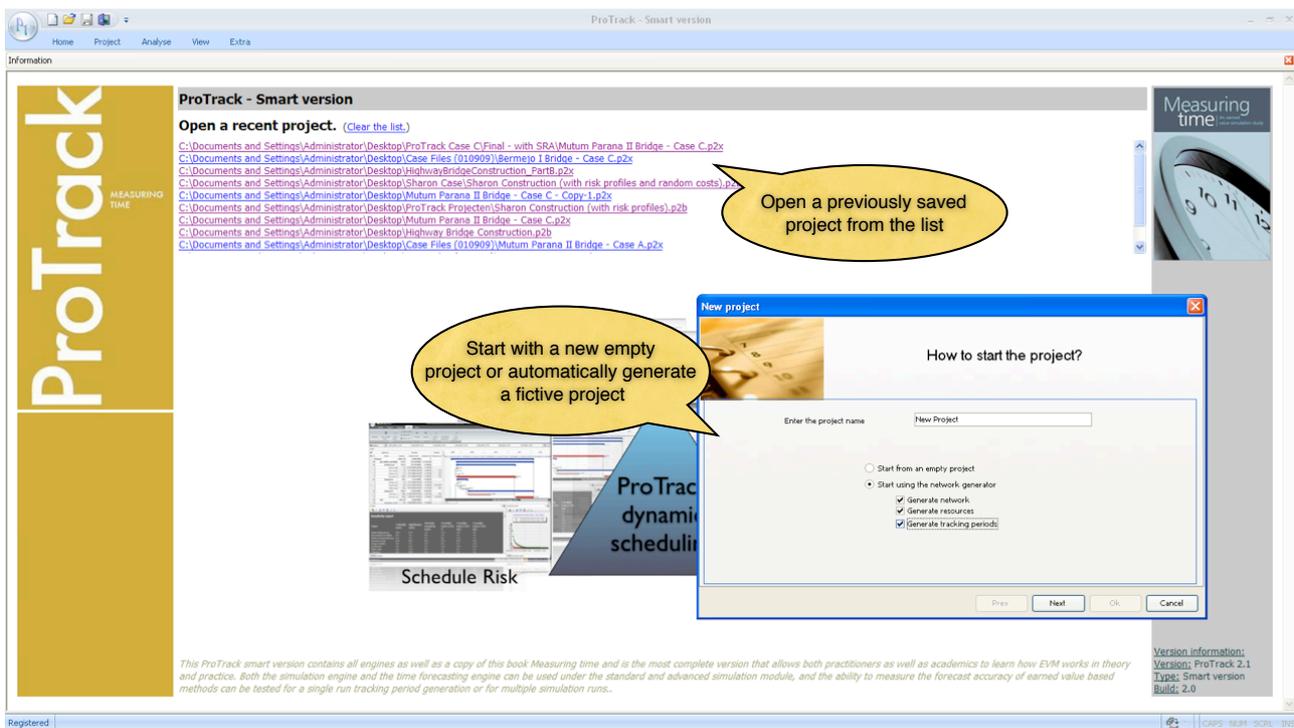


Figure 2.1. The ProTrack welcome and input screen

1.1.2 Automatic project data generation

The generation of fictitious project data is an easy and powerful tool to let you start immediately with ProTrack to gain experience with all its features even before entering real project data. The project data required for ProTrack's baseline scheduling is discussed in sections 1.3 to 1.6 and can be generated automatically using the following data fields:

- Network generator:
 - Number of activities: Number of tasks in the project network.
 - Precedence relations: The number of links between activities is measured by the Serial/Parallel (SP) indicator which indicates how close the project network lies to a complete parallel (no links) or complete serial (maximum number of links) project. This will be explained below at subsection "project network parameters".
 - Time and cost estimates: The time and cost estimates for each activity will be generated randomly from a user-defined interval (see section 1.6).
 - Activity constraints (see section 1.4):
 - Percentage of tasks with constraints (0 - 100%): Randomly adds activity constraints to project activities.
 - Violate project deadline (min - max): Activity constraints imply a certain date in the project life. The minimal project time window is equal to the critical path (*min*). This time window can be extended to maximum the double of the critical path (*max*), and the constraints will be randomly assigned in this time window interval.
 - Feasible (yes/no): Activity constraints can lead to scheduling conflicts and infeasibilities. Putting the feasible option on avoids these constraints conflicts. In section 2.2, the activity constraint hardness options to deal with constraint conflicts are discussed in detail.
- Resource generator: the renewable and consumable resources and their corresponding costs (see section 1.5) can be generated under a user defined design. The parameters to link the activities to resources in order to generate activity resource demand and resource availability can be generated

using several input parameters which will be described in the subsection “resource scarceness parameters”.

- **Project tracking generator:** ProTrack can easily generate fictitious project tracking periodic reviews that help the user to get acquainted with the project control and earned value management concepts. This will be done by the use of the standard simulation engine, which is explained in the “Schedule Risk Analysis with ProTrack” chapter.

Project network structure

The structure of a project network is measured and determined by the set of project activities and precedence relations (links) between them. ProTrack calculates this so-called *topological network structure*¹ using four indicators between 0 and 1. The intuitive meaning of the four indicators is briefly discussed along the following lines. An indication is given of their meaning for the extreme values 0 and 1, but obviously, all intermediate values can be generated in ProTrack.

- **Serial/Parallel Indicator (SP):** Measures how closely the project network lies to a 100% parallel (SP = 0) or 100% serial (SP = 1) network. This indicator can be considered as a measure for the amount of critical and non-critical activities in a network. This network parameter is an input parameter during project generation, while the three others are output parameters.
- **Activity Distribution (AD):** Measures the distribution of the activities along the network, from a uniform distribution across the project network (AD = 0) to a highly skewed distribution (e.g. a lot of activities in the beginning, followed by only a few activities near the end) (AD = 1). Consequently, the AD indicator serves as a measure for the workload variability.
- **Length of Arcs (LA):** Measures the length of each precedence relation between two activities as the distance between two activities in the project network. A project network can have many precedence relations between two activities lying far from each other (LA = 0) and hence, most activities can be shifted further in the network. When all precedence relations have a length of one (LA = 1), all project activities have only immediate successors with little freedom to shift.
- **Topological Float (TF):** Measures the degrees of freedom for each activity as the amount of slack or float an activity has in the project network. TF = 0 when the network structure is 100% dense and no activities can be shifted within its structure. A network with TF = 1 consists of one serial chain of activities without topological float (this chain defines the SP value) while the remaining activities have a maximal float value.

¹ The topological structure of a network is determined by the set of activities and the precedence relations between these activities.

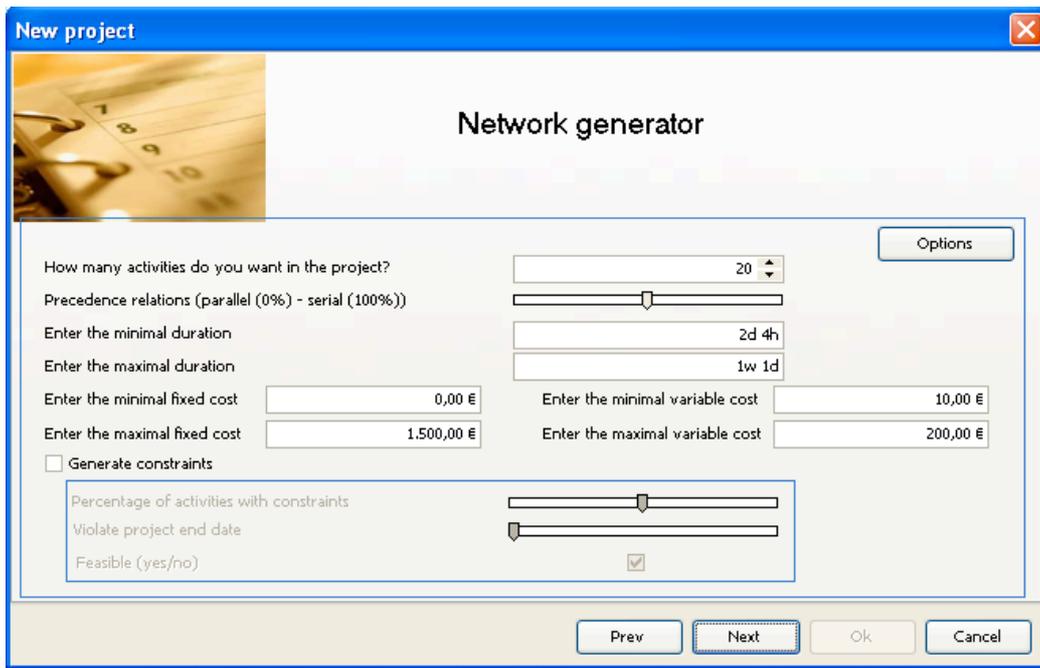


Figure 2.2. The settings of the automatic project network generator

The project network generator screen is shown in figure 2.2. The value of these four topological structure indicators can be called for each project network via the **Analyse - Show Graph - Baseline - Topological Indicators** menu (figure 2.3).

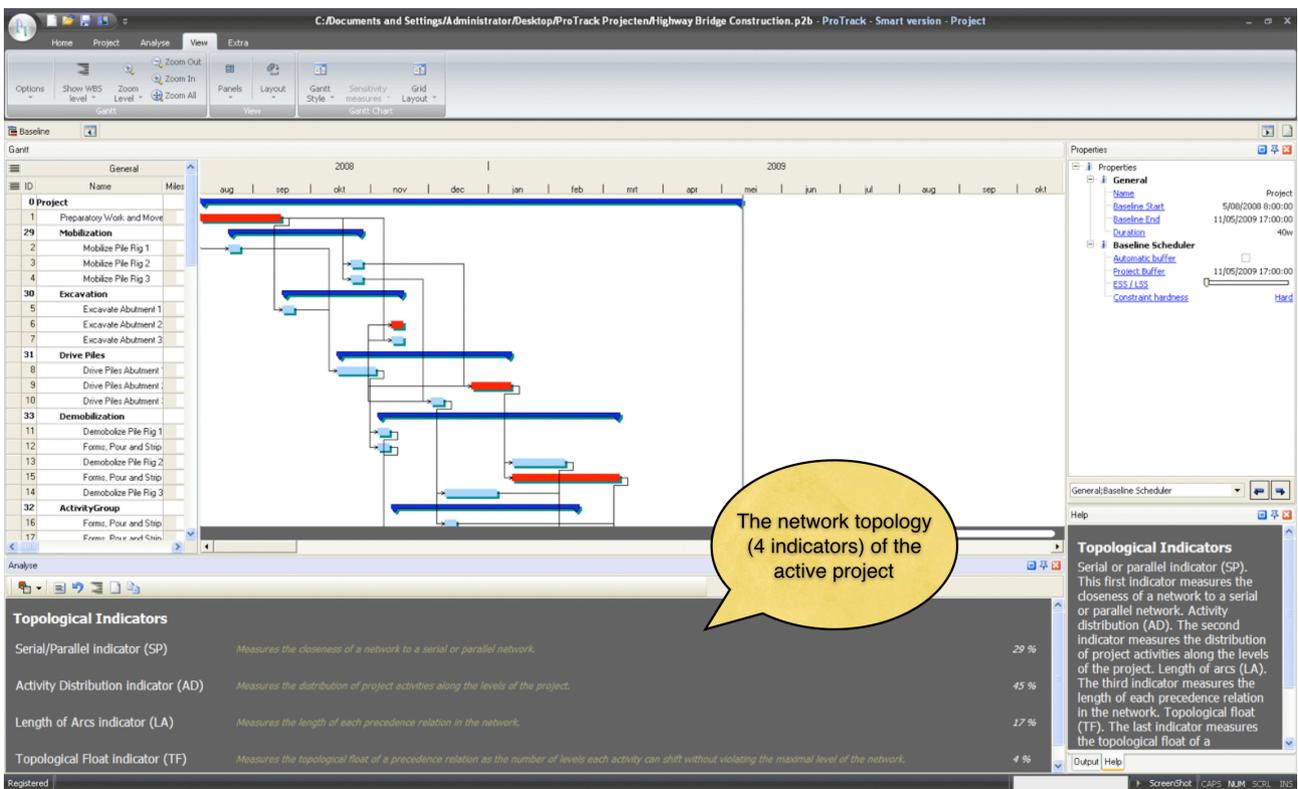


Figure 2.3. The topological network structure calculations in ProTrack

The use of indicators to measure the structure of a project network has been illustrated in numerous research papers. ProTrack’s accompanying book “Measuring Time - Improving project performance using

Earned Value Management” makes use of these indicators to determine the ideal level of project control in the Work Breakdown Structure (WBS).

Resource scarceness structure

Resources are often seen as the bottleneck in projects due to their (high) cost and often limited availability over time. The parameters to link the activities to resources in order to generate fictitious activity resource demand are as follows:

- **Renewable resources:**
 - Resource use: Average number of activities used by each resource (0% to 100%).
 - Average demand: Average resource demand for each activity expressed as a percentage of the resource availability (0% to 100%).
- **Consumable resources:**
 - Resource use: Average number of activities used by each resource (0% to 100%).
 - Percentage fixed demand: Percentage of activities with ‘fixed use’ demand (0% to 100%, remaining portion of activities have a variable demand, see section 1.6).
 - Maximum units: The maximum number of units of the resource requested by the project activities.

The screen of the resource generator is displayed in figure 2.4.

The screenshot shows the 'Resource generator' dialog box. It is titled 'New project' and 'Resource generator'. The dialog is divided into two main sections: 'Renewable resources' and 'Consumable resources'. Each section has a 'Generate' checkbox and a set of sliders for 'Resource use' and 'Average demand' (or 'Average fixed demand'). There are also input fields for 'Minimal cost/use/unit' and 'Maximal cost/use/unit'. At the bottom, there are buttons for 'Options', 'Prev', 'Next', 'Ok', and 'Cancel'.

Figure 2.4. The settings of the automatic resource generator

Note

- * Obviously, both project network and resource scarceness parameters will lead to fictitious projects with little or no meaning to the projects of the user. These automatic generations should not replace the input of real project data, but rather serve as a tool to quickly and easily generate project data under a controlled and user defined parameter setting which allows the user to get acquainted with ProTrack as well as all its underlying project management concepts.

1.1.3 Import project data from MS Project

The import function is not shown on the start screen, but is accessible via the [Home - Import](#) menu. Note that importing an MS Project file in ProTrack requires that MS Project is installed on your computer.

1.2 Project calendar

Each project needs a calendar where days-on and days-off, and working and non-working hours can be specified in advance. The project calendar will be shown automatically upon the start of a new project, or is accessible at any time via the [Project - Agenda](#) menu (see figure 2.5).

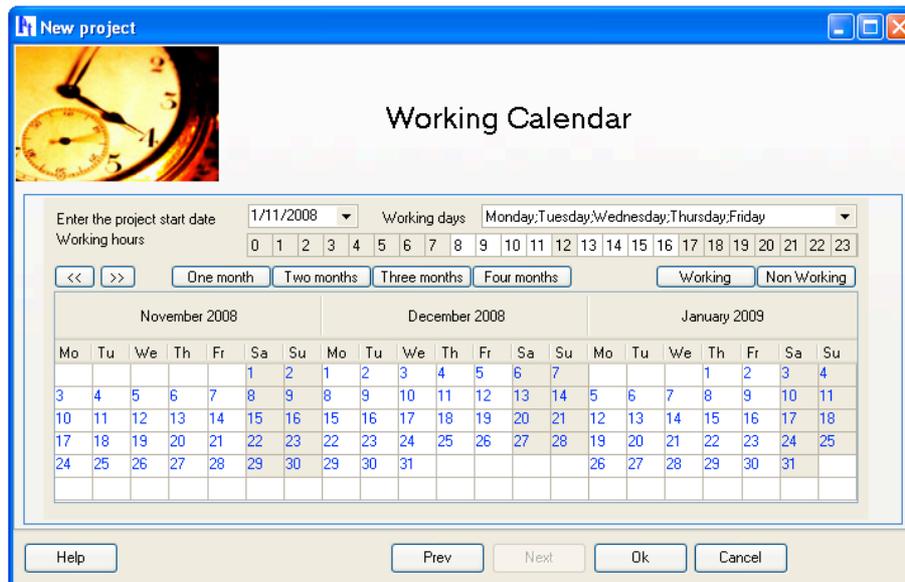


Figure 2.5. The project working calendar

1.3 Project network

A project requires data needed to construct a baseline schedule, which can be summarized along the following lines:

- ID: Automatically generated activity ID.
- Name: Manually chosen activity name.
- Milestone: An activity milestone has a zero duration and cost.
- WBS: Work Breakdown Structure ID of the activity.
- Critical: Indication whether an activity lies on the critical path or not.
- Duration: Estimate of baseline duration expressed in hours, days, weeks or years, e.g. 5h, 5d, 5w or 5y.
- Baseline Cost: Fixed cost and/or variable cost: Estimate of baseline cost expressed in various monetary units, e.g. 3500€
- Start: Activity start date in the baseline schedule.
- End: Activity finish date in the baseline schedule.
- Predecessors: List of activities that immediately precede the current activity through precedence relations.
- Successors: List of activities that immediately succeed the current activity through precedence relations.

The predecessor and successor fields determine the precedence relations between project activities, which can be categorized into four classes. Each category requires a minimal time-lag of x time periods (e.g. 2d, 3w, etc).

- Finish-Start (FS): An activity can only start x days after the finish of its predecessor activity.
 - e.g. 1FS+ x d (predecessor field) or FS2+ x d (successor field).
- Finish-Finish (FF): An activity can only finish x days after the finish of its predecessor activity.
 - e.g. 1FF+ x d (predecessor field) or FF2+ x d (successor field).
- Start-Start (SS): An activity can only start x days after the start of its predecessor activity.
 - 1SS+ x d (predecessor field) or SS2+ x d (successor field).
- Start-Finish (SF): An activity can only finish x days after the start of its predecessor activity.
 - 1SF+ x d (predecessor field) or SF2+ x d (successor field).

Precedence relations can be entered manually in the Gantt chart grid or by drawing the relation between two activities on the Gantt chart (when the  symbol appears on the activity, ProTrack is ready to add a new relation).

The project data can be displayed in the Gantt chart grid ([View - Options - Show Grid](#)) or on the Gantt chart view ([View - Options - Show Gantt](#)). The settings for the time zone and cost formats (e.g. currency format) can be changed in the [Project - Options](#) menu (see figure 2.6).

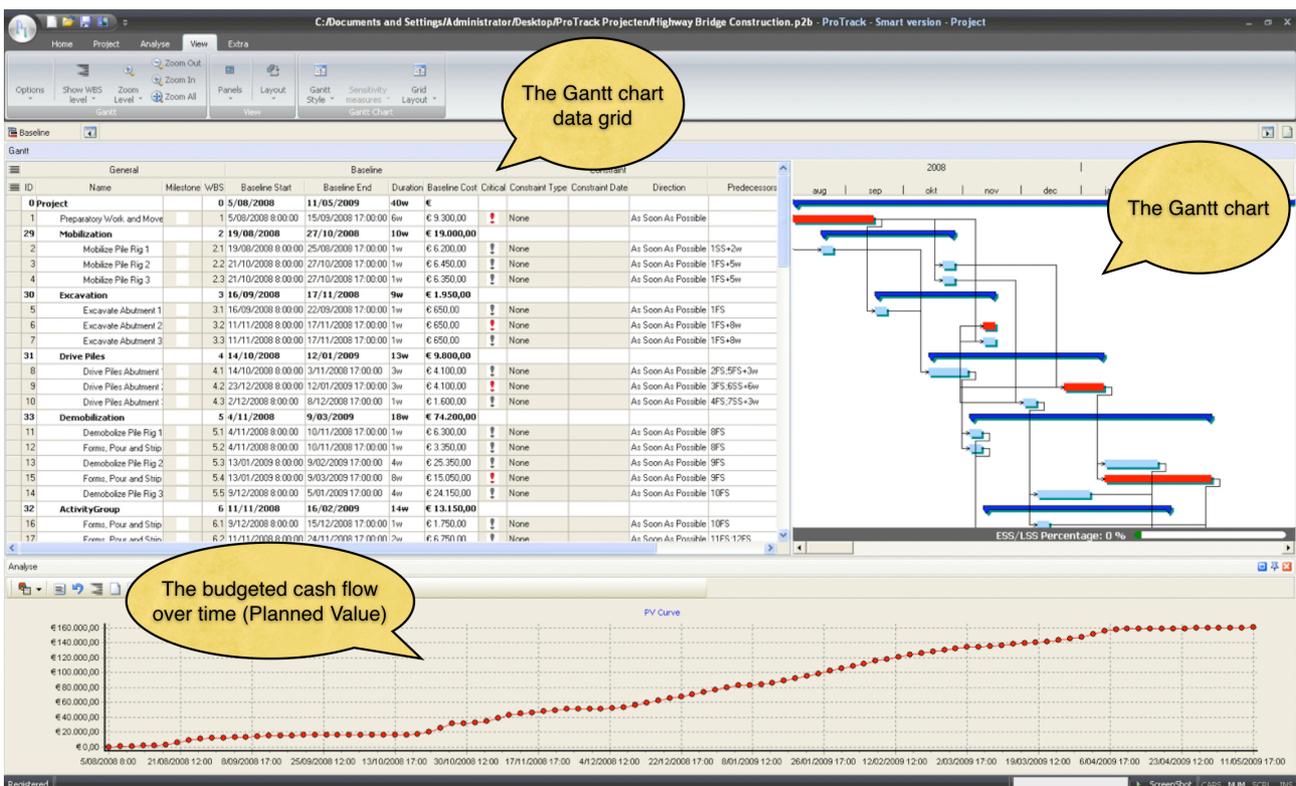


Figure 2.6. The baseline input grid, the Gantt chart and the Planned Value graph

Note

- * Time-lags between activities can be positive as well as negative (e.g. 1FS-2w).
- * Be careful with activities without predecessors or successors. They are considered as activities without any relation, and can be shifted from the start till the finish of the complete project duration.
- * Activities can be combined in activity groups by selecting the activities and using the **Project - Group Tasks** menu. Adding a new activity to a group can be done by right clicking on the activity and selecting the indent option (only works if the task above the selected activity belongs to a group). Removing an activity from a group can be done by right clicking on the activity and selecting outdent. These user actions can also be done by drag and drop user interactions.
- * The fields of the Gantt chart grid (i.e. the table to the left of the Gantt chart) can be changed in the left upper corner of the grid. The first row of the left upper corner shows different data classes (general, baseline, tracking, etc.), while the second left upper corner displays the fields that can be shown in the data grid (see figure 2.7). These settings can be saved for later use by right clicking and following **Grid Layout - Save Current**.

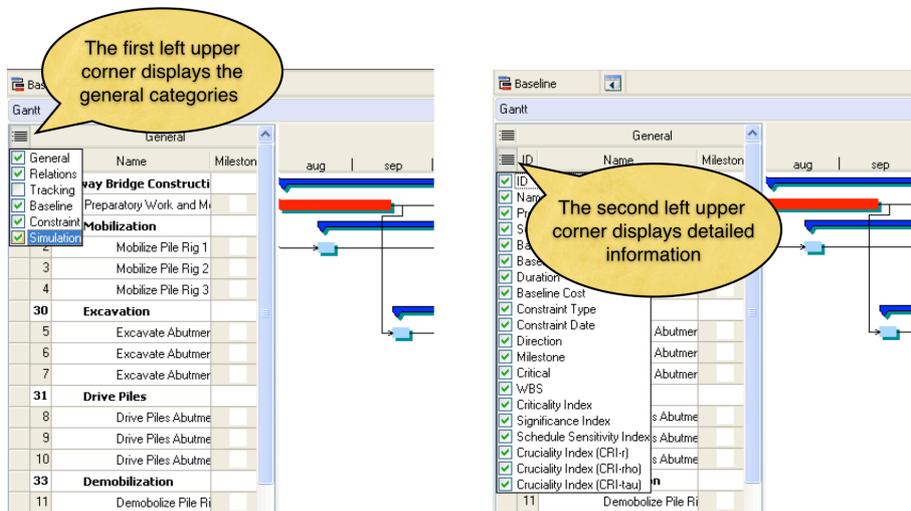


Figure 2.7. Changing the display of the Gantt chart grid

1.4 Activity constraints

Activity constraints can be imposed when there is a need to control the start or finish of an activity. ProTrack contains three types of activity constraints, each having a start and a finish version, as follows:

- **Ready dates** imply earliest start or finish times on activities and hence force the activity to start/finish no earlier than the defined time instance. These constraints are known as ready start time (RST) or ready finish time (RFT).
- **Due dates** imply latest start/finish times on activities and force activities to start/finish no later than a predefined time instance. In ProTrack, these constraints are referred to as due start time (DST) or due finish time (DFT).
- **Locked dates** imply a fixed time instance and force the activity to start/finish on a predefined time instance, known as locked start time (LST) or locked finish time (LFT).

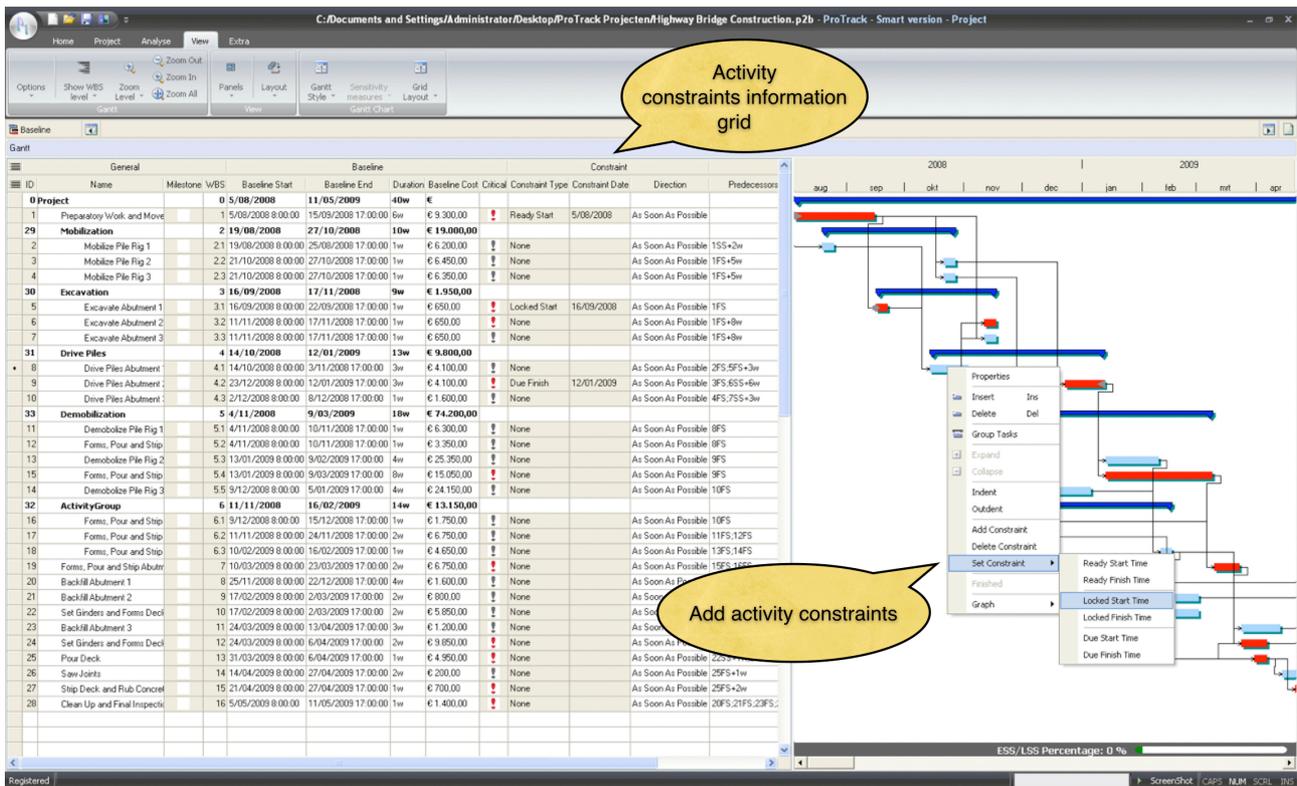


Figure 2.8. Adding activity constraints in ProTrack

Warning

- * Activity constraints are optional and need to be used with care. They limit the scheduling degrees of freedom and restrict ProTrack to make automatic adaptations.
- * The effect of adding constraints to a project schedule varies along the four possible *constraint hardness* modes in ProTrack. These effects are discussed in section 2.2.
- * A constraint can be easily added by right clicking on the activity and setting the possible constraints at the current start or finish time of the activity (see figure 2.8).

1.5 Resource constraints

In the previous sections, it is assumed that project activities do not require resources during their execution (or alternatively, the assumption is that the resources are unlimited in availability). In practice, activities need resources during their execution that are often limited in availability. These resources have been classified in two basic categories.

- Renewable resources are available on a period-by-period basis, i.e. the available amount is renewed from period to period (i.e. per hour). Only the total resource use at every time instant is constrained. Typical examples are manpower, machines, tools, equipment, space, . . .
- Consumable resources are not constrained on a periodic basis but have a limited consumption availability for the entire project. Typical examples are money, raw materials, energy, . . .

Allocating resources to activities

Allocating resources to activities links the resources and their corresponding costs to individual activities and creates values for the activity's resource demand. When the demand for a resource is higher than its availability (since the resource is allocated to various activities scheduled at the same time), it is said that

this resource is over-allocated. ProTrack can try to solve over-allocations of resources by automatically shifting activities in time, as discussed in section 2.5.

The allocation of resources to activities can be done in various ways, as follows (see figure 2.9):

- Right-click on activity and select **Assign Resources** (also available using the Resource Demand input field in the Gantt grid).
- Right-click on resources and select **Show Assignments** (also available using the Assign input field in the Resources grid).

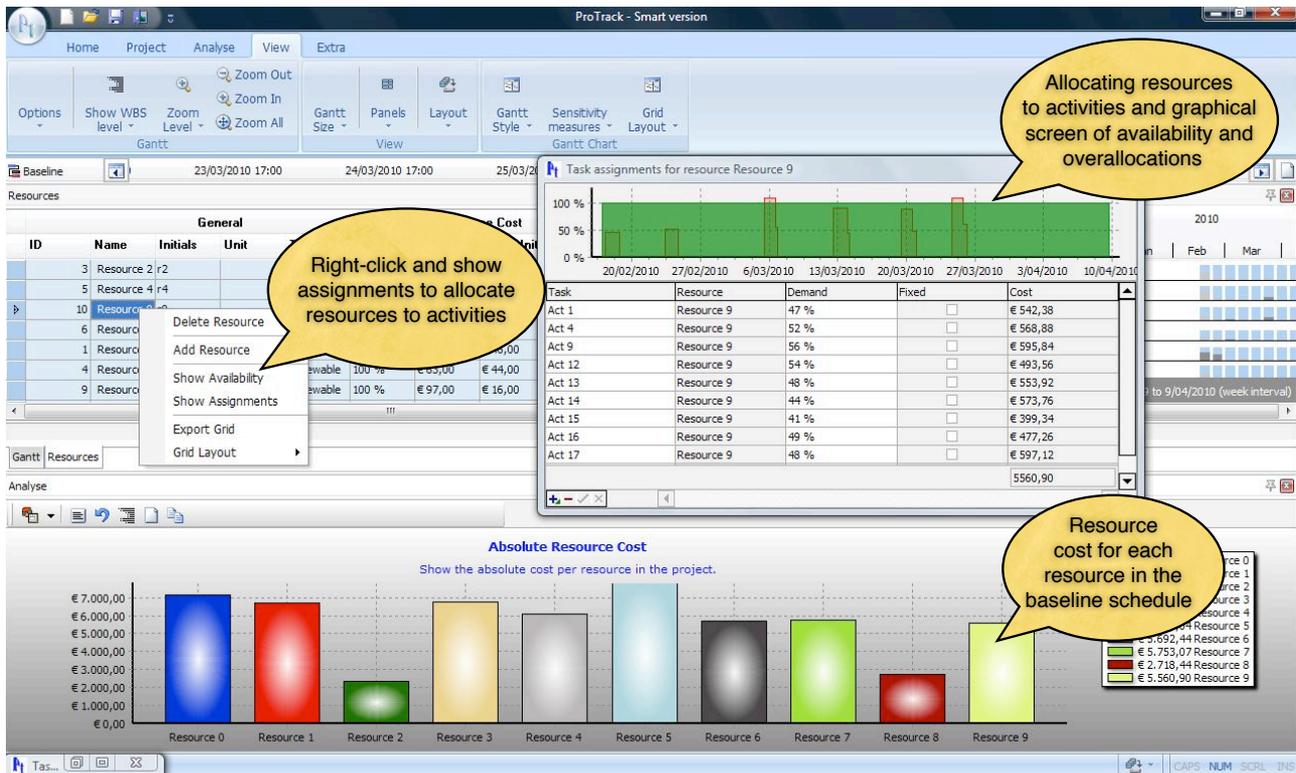


Figure 2.9. Resource allocations in ProTrack

Entering resources in a project requires input data, which can be summarized along the following lines:

- ID: Automatically generated resource ID.
- Name: Manually chosen resource name.
- Initials: Abbreviation for the resource ID, which can be used to quickly assign activities to resources.
- Unit: Unit of the resource. The default unit is expressed in percentages, but it can easily be changed to a user defined unit. As an example, the resource “people” can be expressed in the default percentage (e.g. 300% means that three people are available) or changed to e.g. #persons (e.g. 3 means that three people are available).
- Type: Renewable or consumable resource.
- Availability: the availability of the resource, expressed in the unit (see earlier), which might differ in time.
- Resource Cost: cost/unit and cost/use, as explained in section 1.6.
- Resource Demand:
 - OverAlloc: true or false, depending on the over-allocations in the baseline schedule.
 - Assigned To: Links between activities and resources (the amount is expressed in the user defined unit)

Resource Graphs

Since resources are often considered as the main bottleneck in a project, their efficient use is key to the success of a project. ProTrack offers a wide range of possibilities that analyze the efficiency of the use of the project resources for a given schedule. The graphs include:

- Cumulative resource requirements graphs per resource show the cumulative increase of the resource use, in monetary terms, along the timeline of the project.
- A graph with over-allocations shows where the bottleneck resources are.
- Comparison graphs showing the absolute resource cost as well as the resource cost relative to the total project budget (i.e. the budget at completion)

1.6 Cost calculations

The calculation of costs is an important aspect of project scheduling and control. In this section, four main types of costs are discussed. A first set of costs is a fixed or variable cost that is set for an activity and not for a resource. A second set consists of a fixed or variable cost for the use of resources when demanded by the various project activities. Their use and calculation depends on the type of resources (renewable versus consumable resources) and their use by the activities of the project.

Activity cost

- Fixed cost: A fixed cost can be assigned to an activity without having any link with its resource assignments. It is a fixed amount of money which is independent of the duration of the activity and the work content for one or more resources assigned to this activity.
- Variable cost: A variable cost per time unit can be assigned to an activity regardless of its use of renewable and consumable resources. It is a variable amount of money which is dependent on the activity duration and can be used to describe resource-independent costs such as activity overhead.

Resource cost (see table 2.1)

- Cost per use: The cost for the use of a resource can be considered as a one-time cost incurred every time that the resource is used by the activity. The per use cost for a consumable resource is applied only once from the moment the resource is used. The per use cost for a renewable resource, however, depends on the resource demand of the activity (i.e. its resource requirement and not its total work content). As an example, the cost per use for a consumable resource like gallons of gasoline needed to feed excavators necessary during a construction project is € 250 per delivery, regardless of the amount of gallons brought per delivery per truck (obviously, this is the cost for delivery and not the cost for the gasoline itself, which will be measured by the cost per unit discussed hereafter). The excavator itself, on the contrary, is a renewable resource and has a per use cost of € 1000. Working with 3 excavators in parallel to finish the activity makes the total per use cost equal to € 3000.
- Cost per unit: Unlike the one-time cost per use, the cost per unit is a cost that typically depends on the amount of the resource demanded by the activity and its duration. The calculation of the total activity per unit cost differs along the resource type, renewable or consumable, as explained along the following lines:
 - Renewable resources: the cost per unit are cost rates calculated per time unit (hours, days, weeks, etc.) and per resource unit and hence are based on the total work content (= activity duration x resource demand) of the activity.
 - Consumable resources: Normally, the use of consumable resources by project activities is expressed in units that are typically different from time units. Consequently, the costs per unit are monetary rates typically not calculated per hour but expressed in other units (per weight, per length, per pallet, etc.). However, there are examples where consumable resource use is

expressed as a time dimension. To that purpose, the assignment of a consumable resource to an activity can be done in two alternative ways:

- Fixed use: the unit for the cost/unit calculation of a consumable resource is anything but a time dimension. It is an indication that the quantity of the resource used by an activity is independent from its duration. A typical example is the cost per unit for materials, such as bricks needed to build a wall, which is equal to € 100 per pallet, regardless of how much time it takes to build that wall. The gasoline example for the excavator could also be considered as a consumable resource with fixed use, since its cost completely depends on the amount used, expressed in gallons, to finish a certain activity.
- Variable use: the unit for the calculation of the cost/unit for a consumable resource can be expressed in a time dimension (hours, days, ...). It is an indication that the quantity of resources used by an activity changes proportionally as its duration changes. In the gasoline example, the resource use could have been specified as the number of gallons needed per day. In this case, it is implicitly assumed that the daily occupation of the excavator is known and more or less stable, and the consumable resource of gasoline then depends on the daily gasoline consumption of the excavator, and hence, on the number of days it takes to finish that activity with the help of that excavator.
- The distinction between fixed and variable use is often a matter of choice made by the project scheduler to express the consumable resource consumption needed to finish that activity. For example, if the assignment units value for a consumable resource is, e.g. 100 tons on an activity with a duration of 10 days, the total resource consumption is 100 tons. However, if the assignment units value for that resource is 100 tons/day (variable), the total resource consumption is 1000 tons (fixed).

Table 2.1. Resource cost options in ProTrack

| | Renewable | Consumable |
|-----------|---|---|
| | <i>limited availability during scheduling</i> | <i>no limited availability during scheduling</i> |
| cost/use | cost/use * resource demand | cost/use |
| cost/unit | cost/unit * activity duration * resource demand | Variable: cost/unit * activity duration * resource demand Fixed: cost/unit * resource demand |

Total cost

The total activity cost is equal to the sum of these cost factors as shown in the formula below. Note that this cost calculation function will also be used during project control, where the duration can be replaced by the actual duration (to measure the cost of an activity in progress at a certain moment in time) or remaining duration (to predict the cost of the remaining portion of the activity). When actual activity costs differ from this formula due to unexpected events, the deviations can be calculated using total cost deviations that are inputs by the user. For more information on activity cost calculations during project control, see the "Project control with ProTrack" chapter.

$$\begin{aligned}
 & \text{Total activity cost} \\
 & = \\
 & \text{fixed activity cost} \\
 & + \\
 & \text{variable activity cost * duration} \\
 & + \\
 & \text{cost/use * resource demand (renewable resources)} \\
 & + \\
 & \text{cost/unit * work content (renewable resources)} \\
 & + \\
 & \text{cost/use (consumable resources)} \\
 & + \\
 & \text{cost/unit * work content} \\
 & \text{(variable consumable resource with unit expressed in time units (hours))} \\
 & + \\
 & \text{of cost/unit * \#units} \\
 & \text{(fixed consumable resource with unit not expressed in time units)}
 \end{aligned}$$

2 Project scheduling

The target of project scheduling is to construct a timetable where each individual activity receives a start time and a corresponding finish time within the predefined precedence relations and the various predefined activity constraints. The scheduling process is based on the traditional critical path based forward (to create an earliest start schedule) and/or backward (to create a latest start schedule) project scheduling calculations aiming to construct a project schedule with a minimal project lead time. An option to level resources, when available, is also incorporated in ProTrack 2.0.

2.1 Manual shifts

The Gantt chart is a central display where ProTrack users can easily modify their project data. Adding constraints, changing activity durations and start or finish times or adding precedence relations can be easily done with a few mouse clicks. Manual shifts to reschedule the project can be done to change activity start and end times in two directions, as follows:

- Forward shift: Activity shift towards the project end (leads to buffer consumption or to a change of the buffer time).
- Backward shift: Activity shift towards the project start (cannot start earlier than the project start given in the agenda).

If the mouse pointer appears in front of an activity on the Gantt chart, three actions can be taken, depending on the symbol that appears, as follows:

-  : Add a connection (precedence relation) with another activity
-  : Increase/decrease the activity duration
-  : Shift the activity forwards (to the end) or backwards (to the project start) in time

2.2 Constraint handling

The use of activity constraints increases your own control to the project schedule but leads to a flexibility decrease for the project scheduling algorithm. Although it can be generally recommended to restrict the use of activity constraints to prevent the construction of a rigid project schedule, ProTrack makes use of four ways to handle constraints in a project schedule, varying the degree of constraint hardness. These hardness options influence the result of user interventions (e.g. a manual activity shift in time, adding a constraint or precedence relation, changing an activity duration, etc.) or software interventions (e.g. rescheduling the baseline schedule, update of tracking information, etc.) on the project schedule. The four constraint hardness modes are as follows:

- **Hard constraint mode:** All activity constraints need to be satisfied at all times. When ProTrack interventions tend to lead to constraint violations, ProTrack will automatically return to the previous schedule and undo the infeasible (user or software) intervention.
- **Moderate constraint mode:** All activity constraints need to be satisfied at all times. When ProTrack interventions tend to lead to constraint violations, the precedence relations will be overruled by allowing a certain degree of overlap between project activities. Consequently, a moderate activity constraint has a higher priority than a precedence relation between two activities.
- **Soft constraint mode:** Activity constraints can be violated due to user or software interventions at any time. However, ProTrack will try to prevent the total number of violations by searching for the best possible schedule to satisfy constraints. In case of violations, a report with the violated constraints will indicate where the overridden requirements occur. This is known as *ProTrack constraint based scheduling*, as discussed later in this section.
- **Forward constraint mode:** Activity constraints are only satisfied into one direction and are treated as forward activity constraints. Consequently, all activity ready times are explicitly taken into account, while locked times and due dates are often ignored: locked times are treated as ready times, which will only be satisfied unless it is not possible due to predecessor activities while due dates are completely ignored and will possibly be violated by user or software interventions at any time.

The constraint hardness mode can be changed by clicking on the [Project - Constraint Mode](#) menu. The activity constraint hardness modes are often a powerful tool to guide and influence your schedule into the right direction, but they need to be handled with care. Three important remarks on these constraints are summarized along the following lines:

Forward constraint mode: This constraint mode often violates certain activity constraint requirements. More precisely, it completely ignores due dates and treats locked times as ready times. Therefore, ProTrack always reports where violated activity requirements occur. This constraint hardness mode is the only available option during project simulation and project tracking, where certain activity constraints (due dates and locked times) set during the construction of the baseline schedule can often not be satisfied due to delays in predecessor activities. More information can be found in the “Project Control with ProTrack” and the “Schedule Risk Analysis with ProTrack” chapters.

Soft constraint mode: Combinations of activity constraints often lead to conflicts that cannot be satisfied all together. While the moderate constraint mode resolves these conflicts by allowing overlaps between activities, the soft mode tries to construct a project schedule where the conflicts are minimized. Consequently, this mode constructs a baseline schedule without activity overlaps such that the deviation between activity constraints and start or finish times is minimal. Each time a change in the schedule occurs (manual shift, adding an activity, etc.), ProTrack recalculates the complete schedule and adds a constraint to each activity that has been manually shifted. This is referred to as *constraint based scheduling* which automatically adds activity constraints to the schedule as follows:

- Forward shift (= towards the project finish): set a ready time at the start of the new activity starting time (RST).
- Backward shift (= towards the project start): set a due date at the finish of the new activity finish time (DFT).

This option is particularly useful when multiple conflicting activity constraints are set. ProTrack automatically generates a baseline schedule which satisfies these constraints in the best possible way, without violating the original precedence relations logic.

Switching from constraint mode: Changing the constraint hardness mode for a current schedule might lead to unexpected activity shifts, complete schedule changes or infeasible schedule solutions and therefore need to be done with care. Since the hard constraint mode is the most strict constraint hardness, switching to this mode can lead to three possibilities:

- The switch can be done without any changes and the constraint hardness is set to the hard mode.
- The switch is not possible with the start times of the current schedule due to constraint conflicts, but leads to no constraint conflicts when every activity is set to its earliest possible start (known as an Earliest Start Schedule (ESS)). In this case, the user has the choice to either undo the constraint hardness mode switch or to switch to an ESS.
- The switch is neither possible with the start times of the current schedule nor with the ESS: undo the constraint mode switch.

2.3 Earliest Start or Latest Start

A project schedule consists of a set of activity start and finish times which can vary between the project start date (as given in the agenda) and the project buffer (which is equal to the project finish plus an optional extra buffered safety time). A default project schedule consists of an *Earliest Start Schedule* (ESS) where all activities are scheduled as soon as possible, given the activity constraints (default constraint hardness mode: hard). A *Latest Start Schedule* (LSS) contains a set of activities scheduled as late as possible within the predefined project buffer. Shifting activities forward or backward results in modified schedules according to the wishes and needs of the user in between an ESS and LSS. The user always has the option to return to the earliest start schedule or latest start schedule, given the current project duration (buffer inclusive).

ProTrack contains two ways to return to an earliest start or latest start: one on the activity level and one on the schedule level (i.e. ESS or LSS):

2.3.1 Activity level

The property screen of each individual activity (shown by clicking on the [View - Panels - Properties](#) menu) shows that each activity has a direction, as follows:

- As Soon As Possible (ASAP): Schedules the activity on its earliest possible start time without affecting the start and finish times of all its predecessor activities and/or its own activity constraints.
- As Late As Possible (ALAP): Schedules the activity on its latest possible start time without affecting the start and finish times of all its successor activities and/or its own activity constraints.

While an activity constraint is an optional field for each activity, the as-soon-as-possible (ASAP, default option) or as-late-as-possible (ALAP) option is required, even without the presence of an activity constraint.

2.3.2 Project level

In order to provide full flexibility to the user, ProTrack offers the possibility to construct schedules in between an earliest start schedule (ESS) and a latest start schedule (LSS). A slider (see figure 2.10) allows the user to automatically shift all activities forwards or backwards within their activity slack (taking into account the current (buffered) project duration as well as possible activity constraints). This creates the possibility to

automatically generate project schedules in between an ESS and LSS and is a very useful tool to manipulate your project's cash flow position over time as shown via the [Analyse - Show Graph - EVM Key Parameters - PV Curve](#) menu. Optimizing cash flows in project scheduling often leads to advantages and creates net present value optimization² opportunities. As an example, when cash flows are delayed when shifting towards an LSS, capital intensive investments can be postponed to the future leading to an overall better total project net present value.

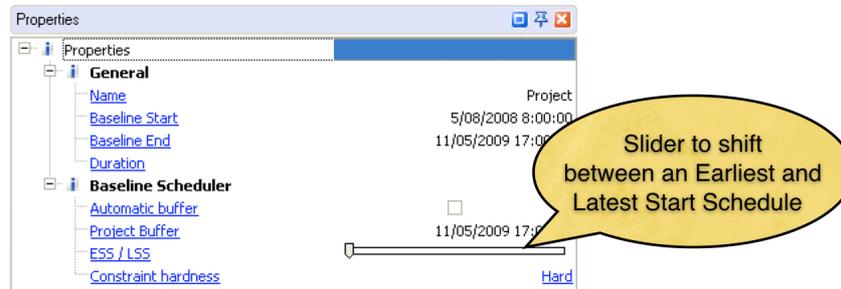


Figure 2.10. Sliding between an ESS and LSS in ProTrack

2.4 Project buffer

A project buffer is an extra time buffer above the project finish reported by the Gantt chart and can be used as an ideal tool for project control during the project tracking phase (see the “Project Control with ProTrack” chapter).

- **Automatic Buffer:** The project buffer is always equal to the project finish, even after project forward and backward shifts.
- **Manual Buffer:** The project buffer is a pre-specified date, and only shifts forwards in time when the project finish exceeds the predefined project buffer.

The role of the project buffer during baseline scheduling is limited to a visualization tool to indicate where the current project schedule lies between the ESS and LSS extremes. However, the project buffer can play a central role during project tracking and serves as a warning signal for buffer consumption to indicate when action is necessary to bring your project back on track. The [Project - Options - Buffer Consumption](#) menu can be used to create a dynamic buffer warning signal tool that divides the buffer consumption into three regions during the tracking periods, as follows:

- Green: Buffer consumption is normal and accepted
- Orange: Buffer consumption is more than normal and deserves attention
- Red: Buffer consumption is critical and actions are necessary

Obviously, the acceptance/attention/action threshold depends on the project's percentage completion, and differs from project to project. Figure 2.11 shows how these thresholds can be set to a user's individual needs.

² See the article by Vanhoucke, M. and Demeulemeester, E., 2003, “The Application of Project Scheduling Techniques in a Real-Life Environment”, *Project Management Journal*, 34 (1), 30-42.

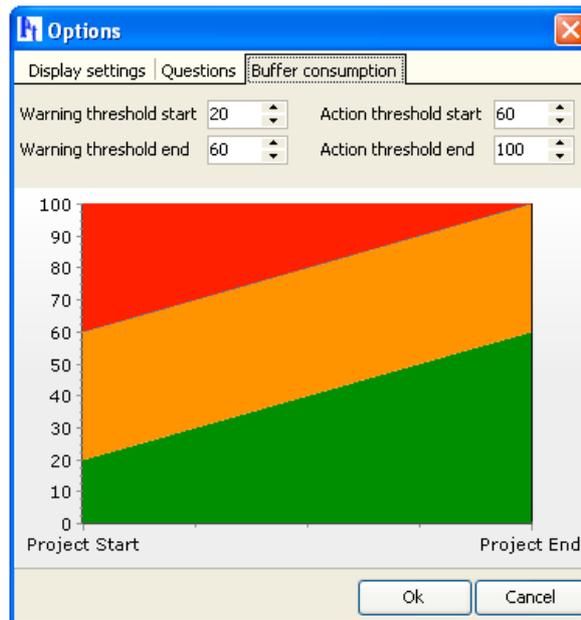


Figure 2.11. Setting buffer acceptance/attention/action threshold in ProTrack

2.5 Resource leveling

Leveling resources is an automatic technique to resolve over-allocations in resource use during the project's life. It is a complex search process which is sometimes controversial to project management software users. It allows the user to automatically delete unwanted over-allocations, but leads at the same time to a sudden change in the schedule that is often incomprehensible to the software user.

ProTrack tries to balance on that fragile bridge between user control and automatic resource optimization by offering state-of-the-art search techniques from the academic literature as well as options to increase control of the user.

The general formula used during leveling of resources (both during baseline scheduling, schedule simulation and project control) is given as follows:

$$\text{WORK CONTENT} = \text{ACTIVITY DURATION} \times \text{RESOURCE DEMAND}$$

ProTrack's resource leveler can be used under two options:

- **Fixed duration:** The duration and resource demand of each activity will never change. ProTrack's resource leveler will shift activities further in time to resolve over-allocations. When no schedule can be found without over-allocations, ProTrack will report that the search did not lead to a successful schedule.
- **Fixed work:** ProTrack will search for a schedule without over-allocations with a fixed work content for each activity. Using this option means that the activity duration and resource demand for each activity can change, such that the work content remains fixed. As an example, an activity with a duration of 2 days and a resource demand of 2 people (i.e. a work content of 4 man-days) can change to an activity with a duration of 4 days only demanding 1 person per day.

After selection of one of the two options, the user can define the intensity of the search to a project schedule without over-allocations, using the two following options:

- Perform full search: ProTrack will search for project schedules until the search is truncated by the user. During the search, ProTrack reports how many project schedules have been evaluated, the number of schedules found without over-allocations and the currently best found project duration.
- Priority rules: priority rules are quick and easy ways to search for a schedule using a ranked list of the project activities following certain criteria. These criteria can be chosen by the user (e.g. random, schedule the shortest processing time activity first, schedule the activity with the most total successors first, etc...) and will be extended upon availability. For more information, the reader should check “priority rule based project scheduling” techniques in the literature.

Note

- * Schedule risk analysis using the standard or advanced simulation engines with resources is always done under a fixed duration mode. For more information, see the “Schedule Risk Analysis with ProTrack” chapter.

3 Baseline schedule

The development of a detailed baseline schedule for measuring schedule performance (time, cost, resources, etc.) as well as to perform risk analyses to detect a project’s most sensitive parts is a crucial step in project scheduling and tracking. The main purpose of the baseline schedule is to act as a point of reference for project tracking (see the “Project Control with ProTrack” chapter) and schedule risk analysis (see the “Schedule Risk Analysis with ProTrack” chapter). In ProTrack, the baseline schedule can be saved by the user, or will be automatically saved from the moment that the first tracking period schedule is constructed.

The current ProTrack version 2.0. supports no re-baselining possibilities, but this will be implemented in the near future. Check our roadmap on www.protrack.be/protrack_roadmap.php to see future development intentions and current work in progress. In the new expected release, ProTrack 3.0 will be able to save as many baseline schedules as the computer memory allows but a strict distinction between the construction of a baseline schedule and the tracking process during project execution will be made. Making changes to the original baseline schedule during project tracking will only be possible by re-baselining the original baseline schedule (i.e. overwrite the current active baseline schedule) and adding it to the current and possible future tracking periods (see the “Project Control with ProTrack” chapter). In doing so, each tracking period schedule will be linked to a single and unique baseline schedule, resulting in a unique and unambiguous point-of-reference for Earned Value metric calculations. However, it should be noted that one should be careful with unwise re-baselining decisions, since this involves a change in the tracking point-of-reference, and hence, previous tracking results are no longer comparable with the current tracking progress state.

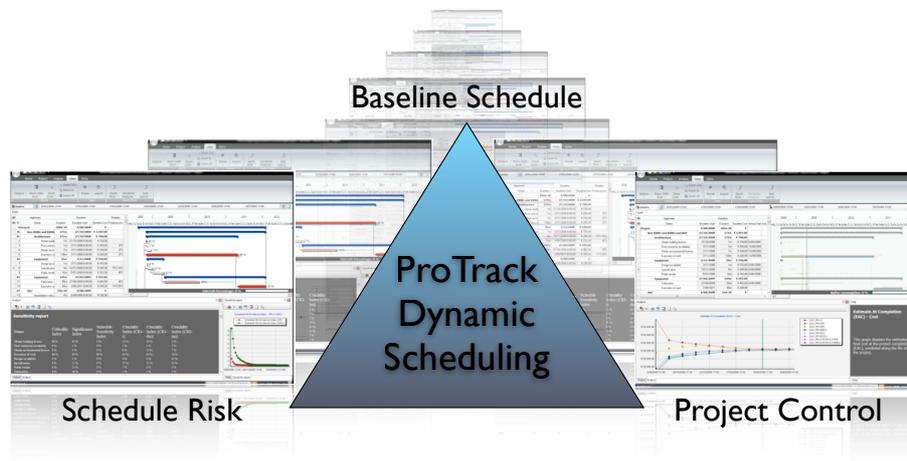
4 Conclusion

Baseline scheduling is a cumbersome task that relies on a project manager’s knowledge about the project scope, activity characteristics and constraints, technological activity relations and reliable time and cost estimates. Although the baseline schedule often fails to reflect reality during the whole project horizon, it plays a crucial role during project monitoring and for a schedule risk analysis.

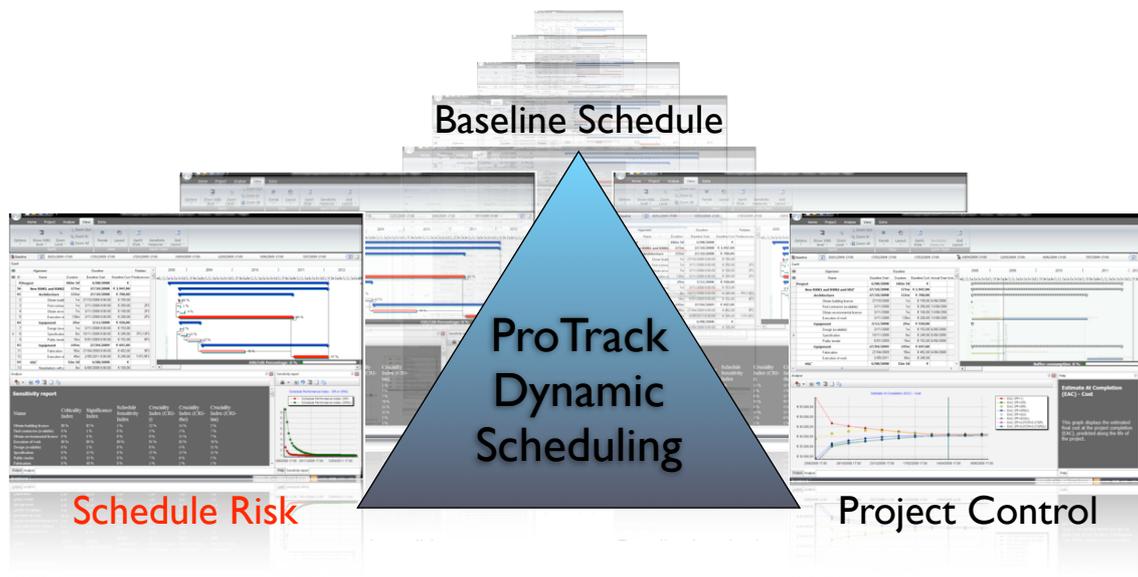
ProTrack’s baseline scheduling offers a balance between project flexibility and schedule constrainedness by offering a combination of automatic scheduling calculations and manual activity restrictions. ProTrack’s basic version offers all baseline scheduling functionalities and many of the project control features. The more

advanced versions (Sensitivity Scan, Time Shuttle and Smart Version) combine all baseline scheduling properties with the more advanced schedule risk analysis and project monitoring features.

It should be noted that the role of a baseline schedule is to act as a dynamic point-of-reference for schedule risk and project control calculations, as implemented in ProTrack's Sensitivity Scan and Time Shuttle versions. For more information, consult the "Schedule Risk Analysis with ProTrack" and "Project Control with ProTrack" chapters.



Chapter 3 Schedule Risk Analysis with ProTrack



The interest in activity sensitivity from both the academics and the practitioners lies in the need to focus a project manager's attention on those activities that influence the performance of the project. When management has a certain feeling of the relative impact of the various parts (activities) on the project objective, a better management focus and a more accurate response during project tracking should positively contribute to the overall performance of the project.

The technique known as **Schedule Risk Analysis** connects the risk information of project activities to the baseline schedule and provides sensitivity information of individual project activities as a way to assess the potential impact of uncertainty on the final project duration.

ProTrack incorporates three simulation engines to perform schedule risk analysis. Through the user of the **Sensitivity Scan** the user can easily perform a Schedule Risk Analysis using the simulation engines. The Sensitivity Scan is available in two ProTrack versions: the Sensitivity Scan Version and the Smart Version.

1 Simulation engines

Three simulation engines are hidden behind the simulation screen of ProTrack. Both engines serve different needs, and can be accessed by a simple click on [Project - New Simulation - Simulation Type](#).

The *standard simulation engine* allows you to start a quick and easy simulation without a thorough study on the risk profiles of the various project activities. The *advanced simulation engine* requires a more detailed risk quantification for each project activity and can be considered as the most advanced Schedule Risk Analysis option in ProTrack. A third *random simulation engine* can be used to arbitrarily generate activity durations during project simulation.

Note that the use of these three simulation engines is not restricted to Schedule Risk Analysis. The engines can be used for two purposes and give access to two options:

- Sensitivity Scan: Allows the user to perform a Schedule Risk Analysis as described in this “Schedule Risk Analysis with ProTrack” chapter.
- Time Shuttle: Allows the user to perform a project performance and forecast accuracy study using Earned Value Management as well as to generate automatic project tracking reports, as described in the “Project Control with ProTrack” chapter.

1.1 Standard simulation

The standard simulation engine consists of 9 predefined scenarios and can be launched by pressing **Project - New Simulation** which shows a sequence of screens with an initial screen with three options:

- 9 standard (EVM) scenarios: This option gives access to the standard simulation and shows a screen as given in figure 3.1.
- Activity risk distribution profiles: This option gives access to the advanced simulation and is discussed in section 1.2.
- Random simulation: This option randomly generates activity times without any user defined information.

When the 9 standard scenarios are chosen, a screen showing 9 possible simulation scenarios appears as shown in figure 3.1.

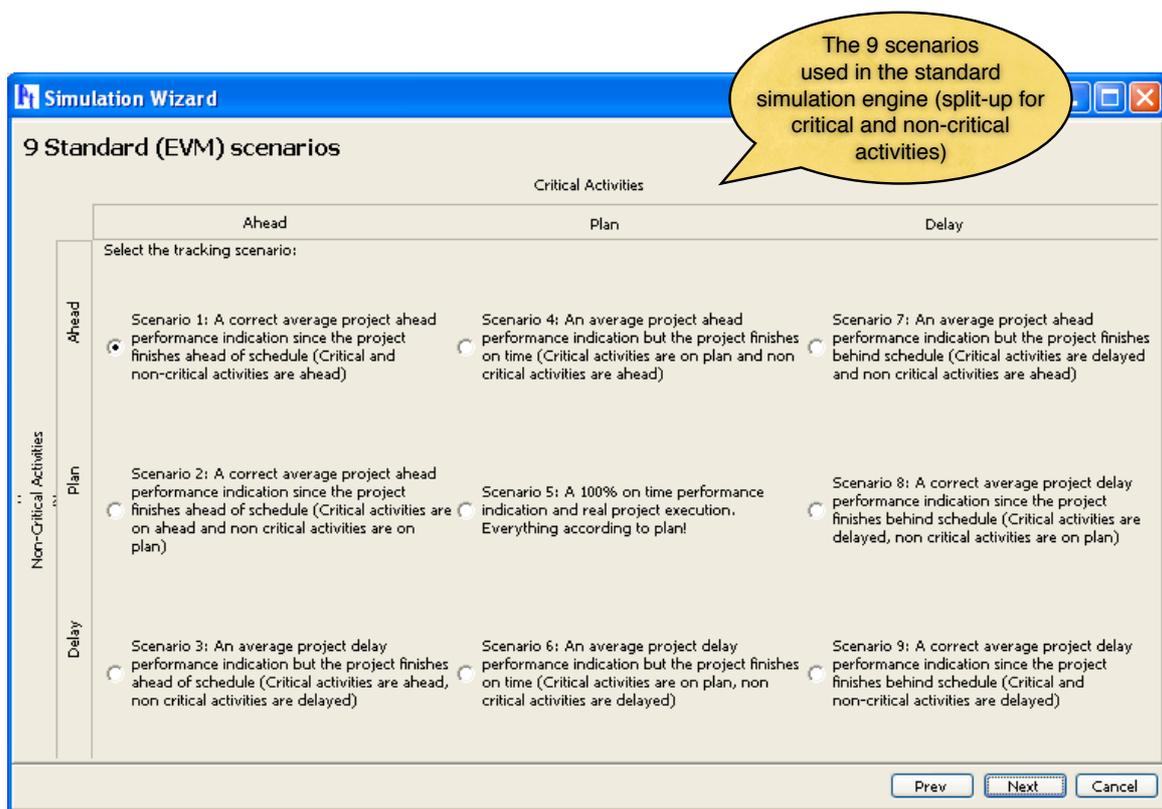


Figure 3.1. The standard simulation engine screen in ProTrack

The standard simulation engine is introduced to the ProTrack user to start an easy and quick simulation study without bothering too much about the activity distributions (as required by the advanced simulation engine) in the project network. The purpose of the nine scenarios is to link them with project performance measurement using Earned Value Management (EVM). Details are described in the “Project Control with ProTrack” chapter.

The nine scenarios can be displayed as follows:

| | | Critical activities | | |
|-------------------------|---|-----------------------------|-----------------------------|-----------------------------|
| | | - | 0 | + |
| Non-critical activities | - | 1. SPI(t) > 1 RD < PD | 4. SPI(t) > 1 RD = PD | 7. SPI(t) > 1 RD > PD |
| | 0 | 2. SPI(t) > 1 RD < PD | 5. SPI(t) = 1 RD = PD | 8. SPI(t) < 1 RD > PD |
| | + | 3. SPI(t) < 1 RD < PD | 6. SPI(t) < 1 RD = PD | 9. SPI(t) < 1 RD > PD |

Legend:

Critical and non-critical activities:

-: activity ahead of schedule

0: activity on time

+: activity delay

EVM Performance measurement (during progress):

SPI(t): average project early warning performance signal

= 1: average 'on time' signal

> 1: average positive signal (ahead of schedule)

< 1: average negative signal (schedule delay)

Final project state (after finish):

RD: Real project duration

PD: Planned project duration

RD = PD: project on time

RD > PD: late project

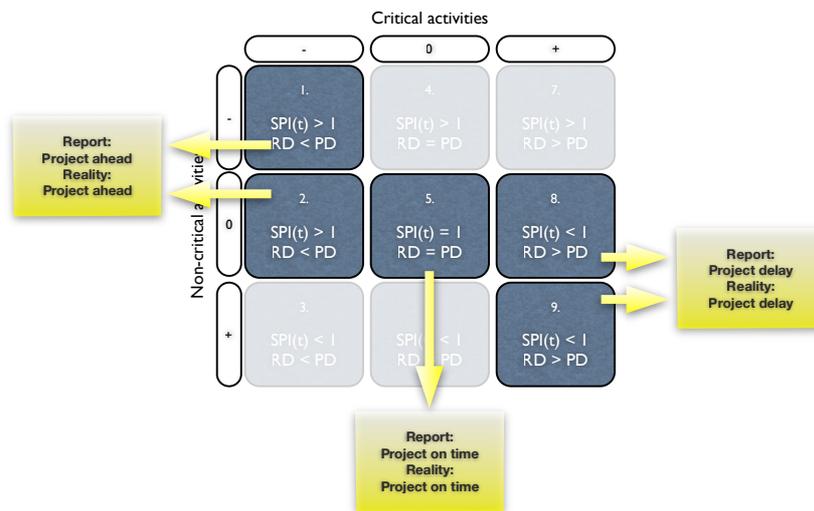
RD < PD: early project

Since the settings of the nine scenarios make the connection between project performance measurement (SPI(t)) and final project status (PD vs. RD), this standard simulation engine cannot be used without the Time Shuttle option as described in the "Project Control with ProTrack" chapter. However, the standard simulation engine can optionally be used to perform a Schedule Risk Analysis using the Sensitivity Scan option. In the current chapter, the focus is restricted to the Sensitivity Scan option, which is discussed in detail in section 2.

The 9 simulation scenarios of the standard simulation engine can be classified into three categories, each having a different meaning and purpose. The interpretation of the 9 scenarios can be summarized as follows:

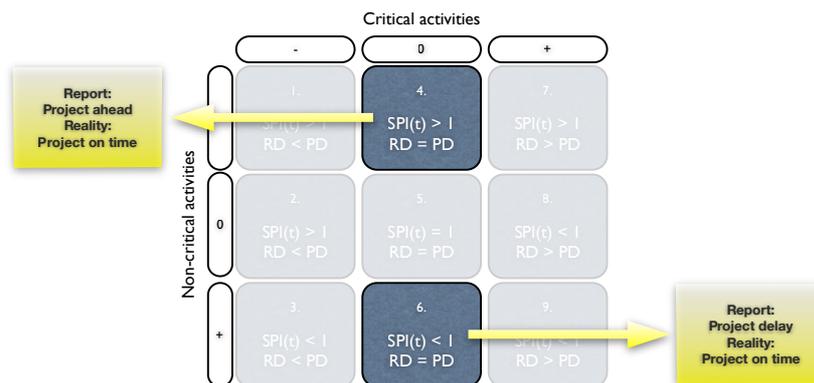
True scenarios

Scenarios 1 and 2 report an average project 'ahead of schedule' progress where the project finishes earlier than planned. Scenarios 8 and 9 report an average 'project delay' progress and the project finishes later than planned. Scenario 5 reports an 'on-time' progress where the project finishes exactly on time. Consequently, these five scenarios report on average a true situation.



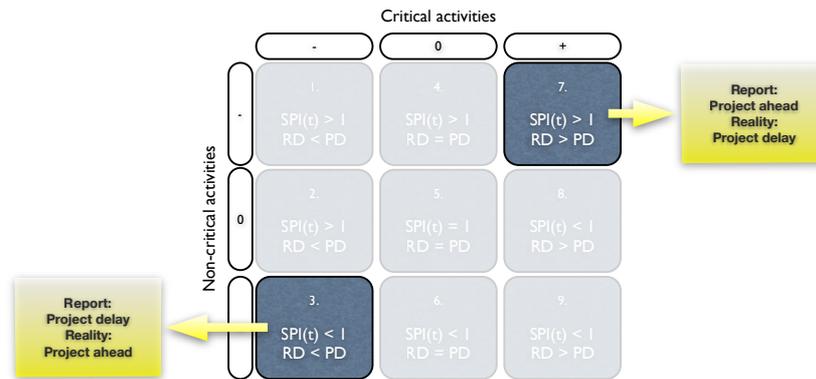
Misleading scenarios

Scenario 4 reports an average project ‘ahead of schedule’ progress but the project finishes exactly on time. Likewise, scenario 6 reports an average ‘project delay’ progress but the project finishes exactly on time. Consequently, these two scenarios report on average a schedule deviation which is not true, and hence, they are called misleading simulation scenarios.



False scenarios

Scenario 3 reports an average ‘project delay’ progress but the opposite is true: the project finishes earlier than planned. Scenario 7 reports an average project ‘ahead of schedule’ progress but the opposite is true: the project finishes later than planned. Consequently, these two scenarios report a false performance signal, and hence, they are called false simulation scenarios.



Warning

- * Be careful with these 9 predefined simulation scenarios. They can be used for easy and quick simulation runs and are particularly useful to learn how EVM works under different circumstances (see the “Project Control with ProTrack” chapter for more information), but they can often be considered as “forced” scenarios that do not reflect reality. Otherwise, if you want to simulate more realistic settings where risk profiles reflect real life needs or situations, go to the advanced simulation option discussed in section 1.2.
- * Some scenarios might be irrelevant under certain conditions. In case a project schedule is buffered (see “Baseline Scheduling with ProTrack” chapter) with extra safety time at the end, there is no real critical path and hence, no critical activities. Consequently, many scenarios (1, 2, 3, 7, 8, 9) will be identical to scenario 5, and no deviation between the planned duration PD and the actual duration RD will be simulated.

1.2 Advanced simulation

The advanced simulation engine allows to define risk classes and profiles for each individual project activity, and has been developed to fully support the Schedule Risk Analysis of the Sensitivity Scan (see section 2). However, the advanced simulation engine can also be used in the Time Shuttle option described in the “Project Control with ProTrack” chapter.

In the advanced simulation engine, you can define individual activity distributions for each project activity by using the *distribution drawer* in ProTrack. This allows you to manually draw distributions and save them for reuse for other activities or other projects. It shows that Schedule Risk Analysis is a simple act of expressing time estimates as ranges, rather than as point estimates. These ranges better reflect the activity uncertainty (best case, worst case, average case, etc.) and the estimated probability of each potential activity duration within the range.

ProTrack makes use of two types of activity duration distributions (see figure 3.2), each serving a different need and purpose, as follows:

- Absolute distributions: The distribution is characterized by absolute durations, expressed in hours, days, weeks, etc. Their use is often restricted to a single activity or a group of very similar activities with similar durations.
- Relative distributions: The distribution is characterized by relative durations, expressed as percentages from the baseline duration. Their use is very general and they can be used as risk classes in order to classify the set of project activities to a set of risk profiles.

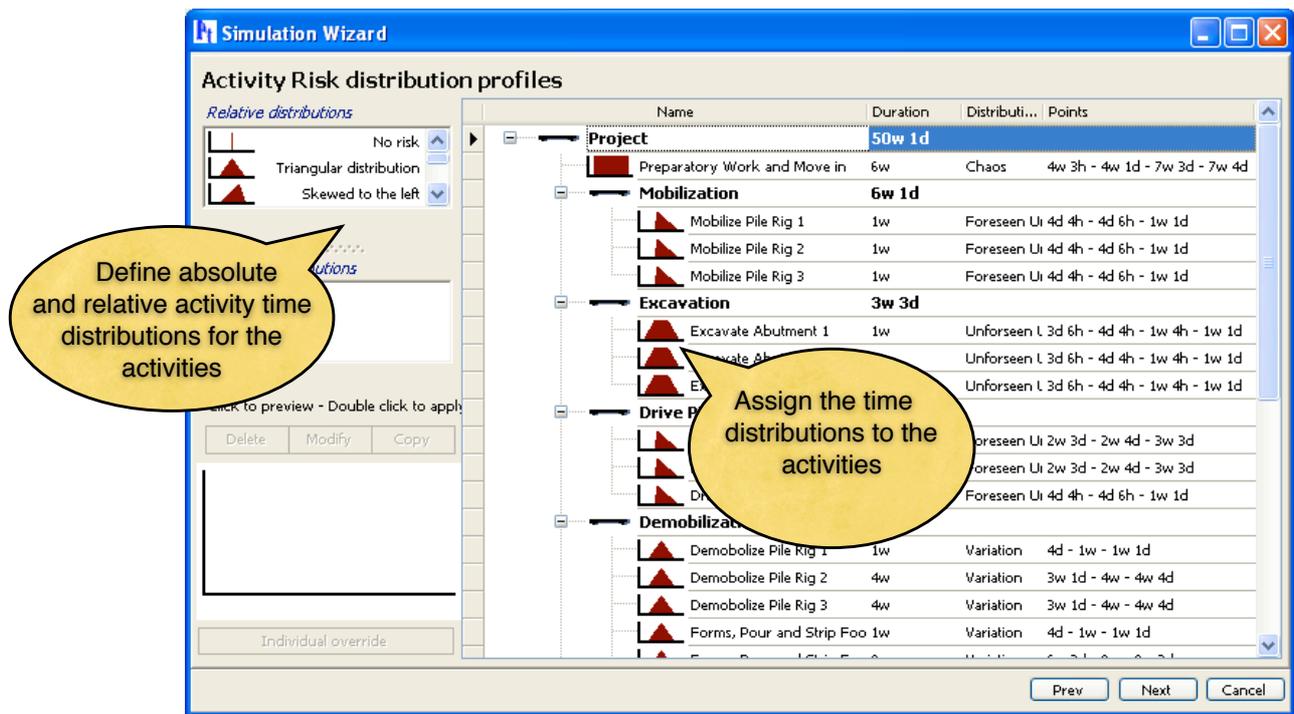


Figure 3.2. The advanced simulation engine screen in ProTrack

The Simulation Drawer of the advanced simulation engine is a simple yet effective tool to define activity risk profiles and to classify the individual project activities into risk classes. The Distribution Drawer starts with a predefined list of four relative activity risk distributions which can be expanded as follows:

- No risk: the activity entails no risk and the duration is a single point estimate.
- Triangular distribution
 - Symmetric: The activity is subject to risk within a certain range, with worst case and best case scenarios symmetric above and below the average.
 - Skewed to the right: The activity is subject to risk within a certain range, where activity delays are more likely than early activity durations.
 - Skewed to the left: The activity is subject to risk within a certain range, where early activity durations are more likely than activity delays.

The list of relative (default 4 distributions) and absolute (default empty) distributions can be changed and expanded by means of four menus as described below:

- Delete: Select an absolute or relative distribution and delete it from the list.
- Modify: Select an absolute or relative distribution and change its risk range and probability level in the 'Sensitivity Distribution Profile' screen.
- Copy: Copy an absolute or relative distribution and change it with the 'modify' button.
- Individual Override: Create or change an absolute distribution. Select the distribution of an individual activity, click on 'Individual Override', and you will enter the 'Sensitivity Distribution Profile' screen. Change the distribution according to your best guess on its risk profile (range and probability) and save it as an absolute activity duration distribution.

The 'Sensitivity Distribution Profile' screen is displayed in figure 3.3 and allows you to graphically define a risk profile (range estimate and corresponding probability) using the settings fields as described below:

- Distribution: Give a name for this absolute or relative activity distribution.

- Settings: Change the way you construct risk profiles for each activity.
- Usage: Short explanation of how to use this screen.

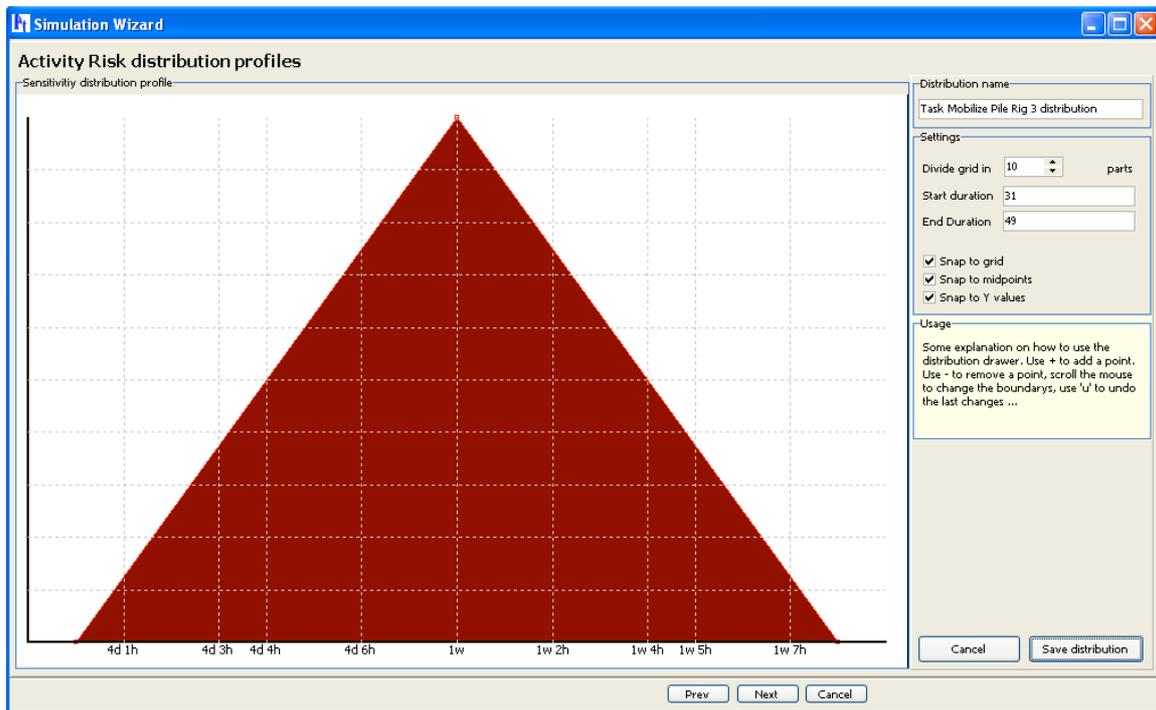


Figure 3.3. The Sensitivity Distribution Profile screen in ProTrack

Risk Classification

The ProTrack advanced simulation engine can be easily used as a risk classification tool for risk analysts to simply classify project activities into a small set of predefined risk categories representing relative distributions. Each distribution has a certain 'class name' and a well-defined meaning of risk, and each activity can be assigned to each of these classes while ProTrack's advanced simulation engine does the rest and provides risk measures for each individual activity.

An example of a risk classification is given below (see figure 3.4). The reader should note that both the names and the meaning of each risk class is only for illustrative purposes, and can vary along the characteristics of the project, the culture of the company, the wishes and needs of the project team, and many more.

- Variation: The activity time estimate is quite reliable, but might be subject to little unexpected changes.
- Foreseen Uncertainty: The activity time estimate is quite reliable, unless a known risk factor shows up. A typical example is a quite reliable time estimate of the project activity, which can be subject to a delay if weather conditions (i.e. the known risk factor) are worse than expected.
- Unforeseen Uncertainty: The activity time estimate is not very reliable and might vary between two extremes.
- Chaos: The activity time estimate is a rough average prediction, and can differ very much from the original prediction in two extremes: much lower or much higher than expected.

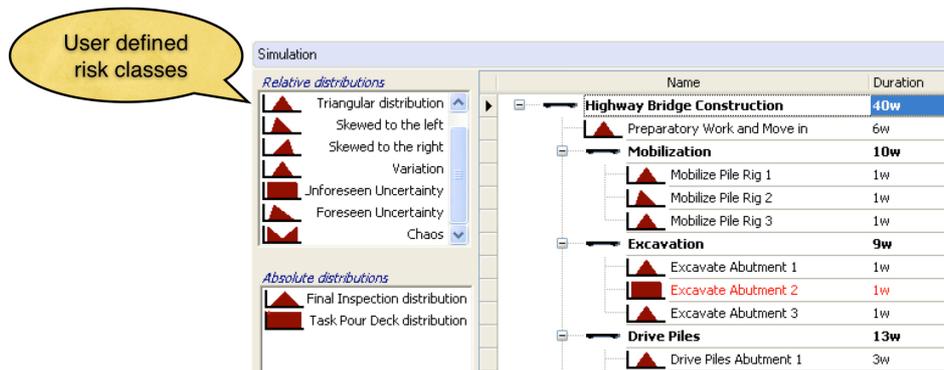


Figure 3.4. Defining relative activity risk classes

1.3 Random simulation

The random simulation engine is a quick and easy simulation that allows the user to randomly generate activity durations that are different from its baseline durations, with the following parameters:

- Percentage Early: Percentage of activities with a duration smaller than its baseline duration (the remaining portion of activities will have a delay).
- Maximum deviation: The maximum percentage of deviation from the baseline duration for each activity.

The main reason why this random simulation has been incorporated in ProTrack 2.0 is to generate automatic tracking periods without much effort of the user. This automatic option is discussed in the "Project control with ProTrack" chapter.

2 Sensitivity Scan

The **Sensitivity Scan** provides sensitivity measures for each individual project activity and gives information on the potential impact of activity uncertainty on the project duration and cost and on the cost of resources. Both the standard and the advanced simulation engines repeatedly simulate project progress to allow the Sensitivity Scan option to scan and measure the sensitivity of the project activities and their resources in the network. The sensitivity scan can be used to measure the time sensitivity of activities, as well as to measure the sensitivity of the total cost of activities and the cost of resources, as briefly shown below.

Time sensitivity. This so-called Schedule Risk Analysis refines the black-and-white view of the critical path (which defines that an activity is either critical or not) to a degree of criticality/sensitivity, as follows:

- Criticality Index (CI): Measures the probability that an activity is on the critical path.
- Significance Index (SI): Measures the relative importance of an activity.
- Schedule Sensitivity Index (SSI): Measures the relative importance of an activity taking the CI into account.
- Cruciality Index (CRI): Measures the correlation between the activity duration and the total project duration, in three different ways:
 - CRI(r): Pearson's product-moment correlation coefficient.
 - CRI(ρ): Spearman's rank correlation coefficient.
 - CRI(τ): Kendall's tau rank correlation coefficient.

Each measure gives you an indication of how sensitive the activity is towards the final project duration as defined by the sensitivity measure. Next to the sensitivity measures outputs, the sensitivity scan also shows

you the probability of the project finish over time, expressed in the “cumulative project duration” graph as shown in figure 3.5.

Total activity cost sensitivity. Uncertainty in activity durations has an influence on the (variable) costs of the activity. This influence can be measured by the three versions of the cruciality index, as follows:

- Cruciality Index (CRI): Measures the correlation between the activity cost and the total project cost (Budget at Completion), in three different ways:
 - CRI(r): Pearson's product-moment correlation coefficient.
 - CRI(ρ): Spearman's rank correlation coefficient.
 - CRI(τ): Kendall's tau rank correlation coefficient.

Resource cost sensitivity. Uncertainty in activity durations has an influence on the resource costs of the activity. For an overview of how resource costs are calculated, see the activity and resource cost section of the “Baseline Scheduling with ProTrack” chapter. This influence can be measured by the three versions of the cruciality index, as follows:

- Cruciality Index (CRI): Measures the correlation between the resource cost and the total project cost (Budget at Completion), in three different ways:
 - CRI(r): Pearson's product-moment correlation coefficient.
 - CRI(ρ): Spearman's rank correlation coefficient.
 - CRI(τ): Kendall's tau rank correlation coefficient.

In the remainder of this chapter, a focus is set on the time sensitivity of the sensitivity scan. A similar approach can be taken for total activity cost and resource cost sensitivity.

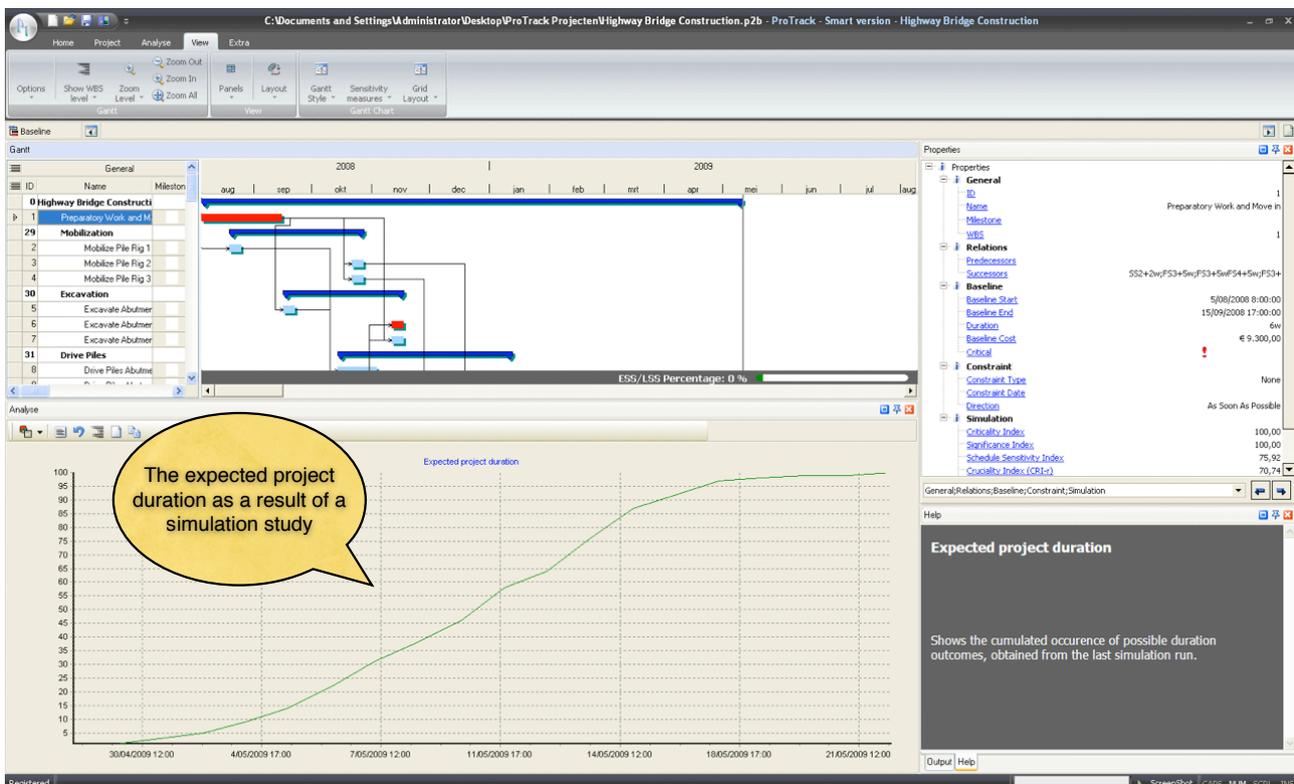


Figure 3.5. The expected project duration obtained from simulations

The values for the sensitivity measures are available upon completion of the simulation runs. They can be accessed by means of a sensitivity report or a sensitivity Gantt chart. The sensitivity report summarizes all

sensitivity measures for the project activities, as shown in figure 3.6. It can be displayed via **Home - Show Graph - Sensitivity Measures - Sensitivity Report**.

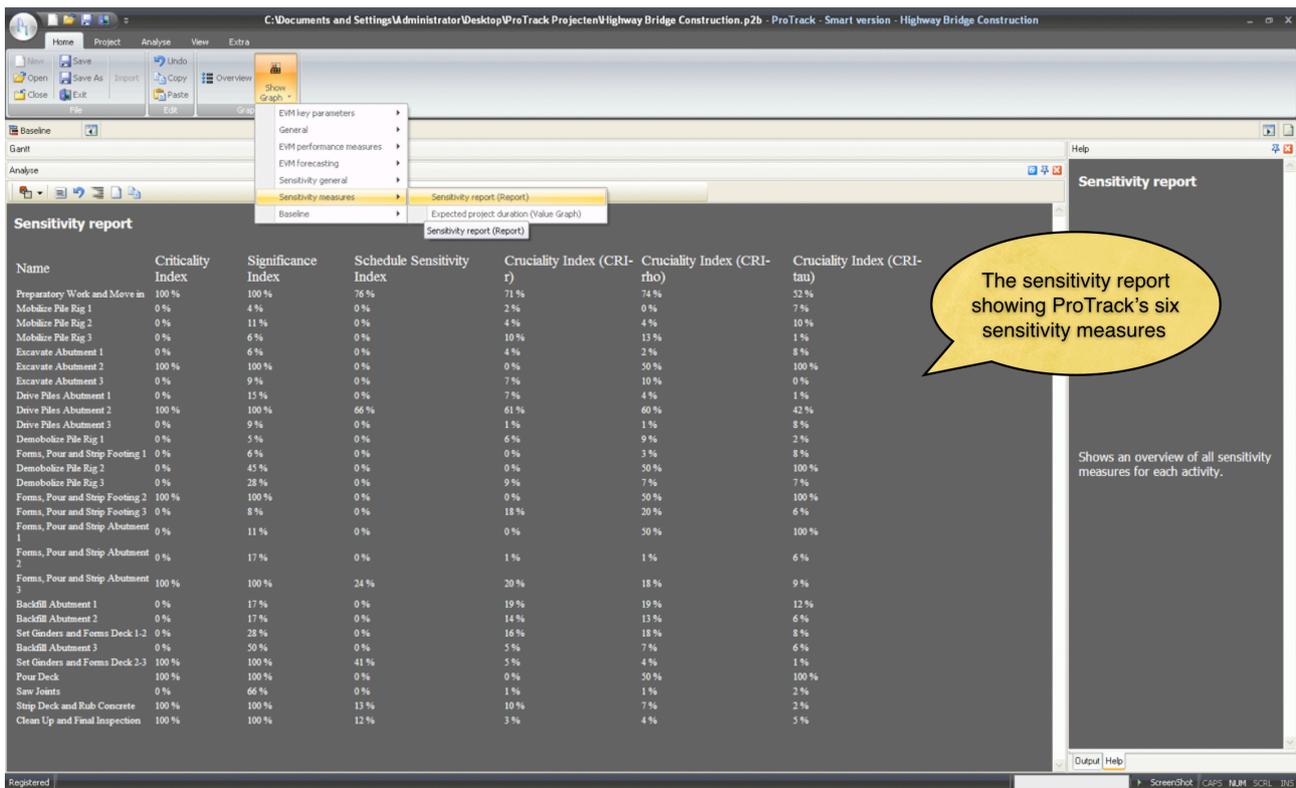


Figure 3.6. The sensitivity report view in ProTrack

Alternatively, a more refined Gantt chart can be constructed via **View - Sensitivity Measures** or **View - Gantt Style - Sensitivity View**. This Gantt chart refines the black-and-white view of the critical path. Indeed, rather than showing whether an activity is risky (on the critical path) or not (not on the critical path), it shows a degree of risk or sensitivity between the risk/no risk range reported by the critical path (see figure 3.7).

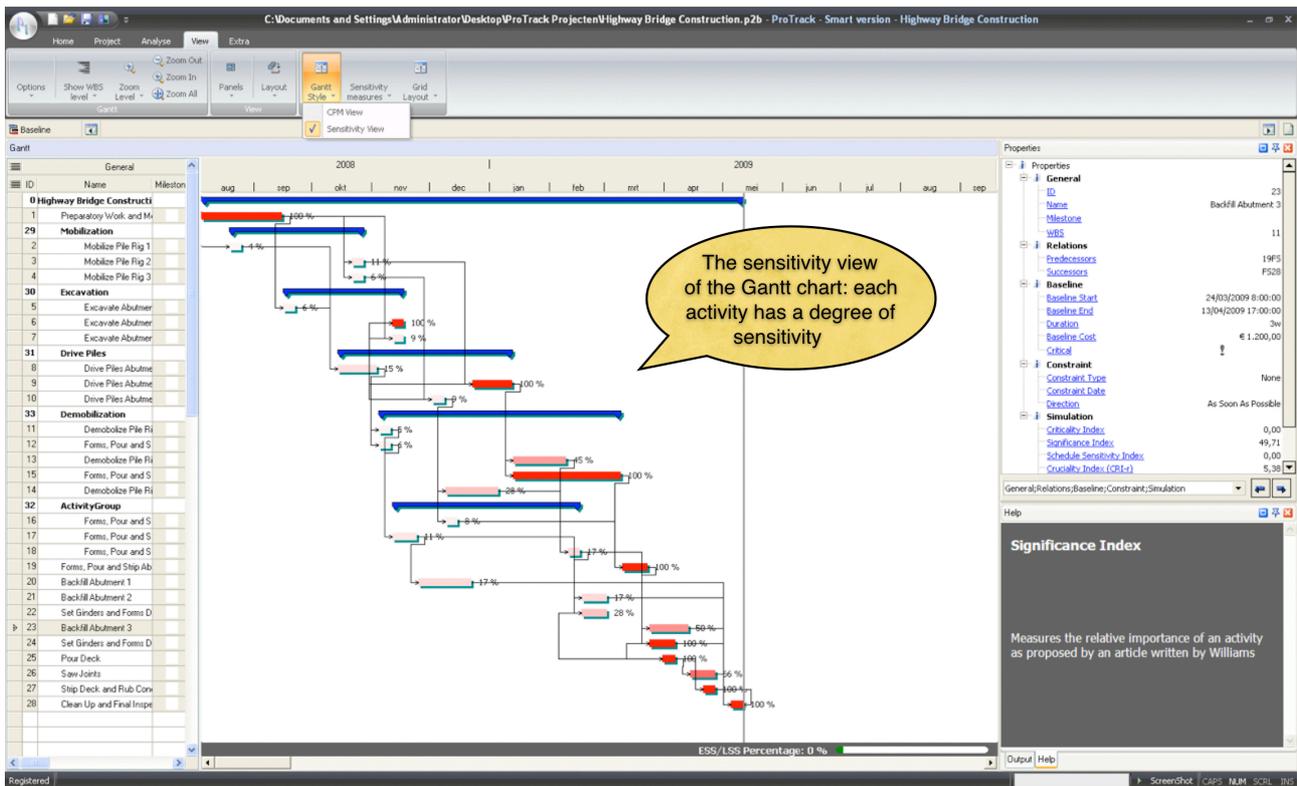


Figure 3.7. The sensitivity view Gantt chart view

Note

- * All simulation results are accessible via the **Analyse - Overview** menu which shows an overview of Project Information (see the “Baseline Scheduling with ProTrack” chapter), EVM Analysis (see the “Project Control with ProTrack” chapter) and Sensitivity Analysis (this chapter). The standard and advanced simulation engines as well as the Sensitivity Scan results are accessible via the Sensitivity Analysis menu.
- * The sensitivity report can also be displayed in the Gantt chart grid (i.e. the table to the left of the Gantt chart). Select ‘Simulation’ in the left upper corner and select the sensitivity measures you want to display in the grid in the second row of the left upper corner (see figure 3.8).
- * Note that the resource cost sensitivity measures show the sensitivity of the cost of resources (and not for the activities) and can therefore not be displayed in the Gantt chart. The three cruciality index values for the resource cost sensitivity can be accessed via the resource grid. More information can be found in the “Baseline scheduling with ProTrack” chapter.

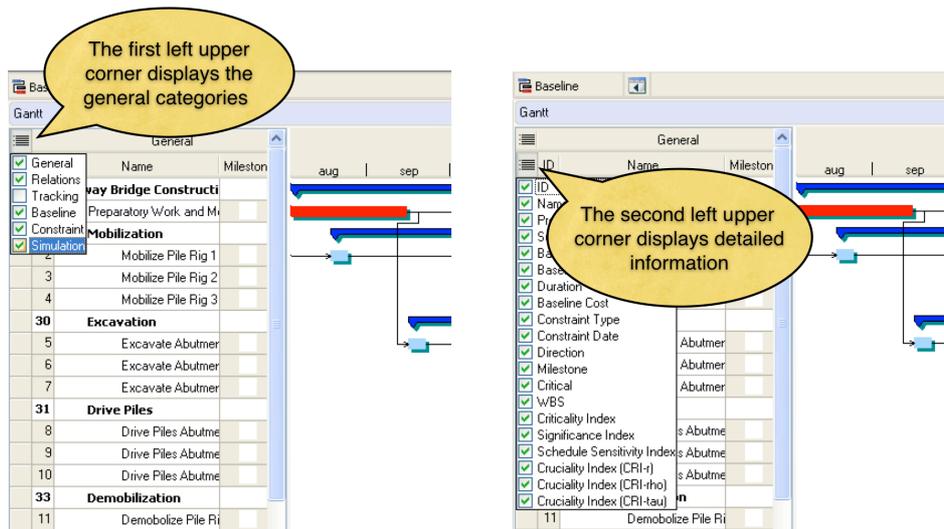


Figure 3.8. Changing the layout of the grid

2.1 Criticality Index (CI)

The Criticality Index measures the probability that an activity lies on the critical path. It is a simple measure expressed as a percentage denoting the likelihood of being critical. Although the Criticality Index has been used throughout various studies and implemented in many software tools, the CI often fails in adequately measuring the project risk. The main drawback of the CI is that its focus is restricted to measuring probability, which does not necessarily mean that high CI activities have a high impact on the total project duration (e.g. think of a very low duration of an activity always lying on the critical path, but with a low impact on the total project duration due to its negligible duration).

2.2 Significance Index (SI)

In order to better reflect the relative importance between project activities, the Sensitivity Index of a project activity can be calculated as follows:

$$SI = E\{(ActivityDuration * ProjectDuration) / ((ActivityDuration + ActivitySlack) * E(ProjectDuration))\}$$

with $E(x)$ used to denote the expected value of x . The SI has been defined as a partial answer to the criticism on the CI. Rather than expressing an activity's criticality by the probability concept, the SI aims at exposing the significance of individual activities on the total project duration. In some examples, the SI seems to provide more acceptable information on the relative importance of activities. Despite this, there are still examples where counter-intuitive results are reported.

2.3 Schedule Sensitivity Index (SSI)

The Project Management Body Of Knowledge (PMBOK) mentions quantitative risk analysis as one of many risk assessment methods, and proposes to combine the activity duration and project duration standard deviations ($StDev_{ActivityDuration}$ and $StDev_{ProjectDuration}$) with the Criticality Index. The Schedule Sensitivity Index is calculated in ProTrack as follows:

$$SSI = (StDev_{ActivityDuration} * CI) / StDev_{ProjectDuration}$$

2.4 Cruciality Index (CRI)

Another measure to indicate the duration sensitivity of individual activities on the total project duration is given by the correlation between the activity duration and the total project duration for the time sensitivity measures. Likewise, the activity cost and resource cost sensitivity can be measured by an alternative version of the cruciality index where the duration parameters are replaced by the cost parameters. Consequently, the cruciality index can be calculated as follows:

$$\begin{array}{ll} \text{CRI} = |\text{correlation}(\text{ActivityDuration}, \text{ProjectDuration})| & \text{Activity time sensitivity} \\ \text{CRI} = |\text{correlation}(\text{ActivityCost}, \text{ProjectCost})| & \text{Activity cost sensitivity} \\ \text{CRI} = |\text{correlation}(\text{ResourceCost}, \text{ProjectCost})| & \text{Resource cost sensitivity} \end{array}$$

This measure reflects the relative importance of an activity in a more intuitive way and calculates the portion of total project duration uncertainty that can be explained by the uncertainty of an activity. ProTrack incorporates three correlation measures which are briefly discussed along the following lines³.

Pearson's product-moment CRI(r) is a traditional measure of the degree of linear relationship between two variables. The correlation is 1 in the case of a clear positive linear relationship, -1 in the case of a clear negative linear relationship, and some value in between in all other cases, indicating the degree of linear dependence between the activity duration and the total project duration. The closer the coefficient is to either -1 or 1, the stronger the correlation between these two variables.

However, the relation between an activity duration and the total project duration often follows a non-linear relation. Therefore, non-linear correlation measures such as the Spearman rank correlation coefficient or Kendall's tau measure can also be calculated in ProTrack. These two correlation measures can be calculated as follows:

Spearman's rank correlation CRI(ρ) (*rho*) assumes that the values for the variables (i.e. activity durations and project durations) are converted to ranks, followed by the calculation of the difference between the ranks of each observation on the two variables. The measure is a so-called non-parametric measure to deal with situations where the strict statistical assumptions of the parametric CRI(r) measure are not met. The CRI(ρ) measure has a similar meaning than the CRI(r) measure, i.e. $-1 \leq \text{CRI}(\rho) \leq 1$.

Kendall's tau rank correlation CRI(τ) (*tau*) index measures the degree of correspondence between two rankings and assesses the significance of this correspondence. This non-parametric measure has a similar meaning than the CRI(r) measure, i.e. $-1 \leq \text{CRI}(\tau) \leq 1$.

Warning

- * Be careful with sensitivity information. The Sensitivity Scan measures give information about the potential effect of uncertainty on the final project duration or cost, but differ all in value. Hence, it is important to correctly interpret these values for your project. Do not interpret what you don't understand. None of these measures give you relevant information without interpretation, but all these measures are constructed to support your decisions in your project.
- * Simulation results might be affected by the calendar specified in the agenda. Small delays in activity durations might lead to larger project delays in case the delay spans a weekend or a holiday period.
- * ProTrack suggests a default number of simulation runs of 100, which can be changed by the user. Note that more simulation runs require more CPU time. As a general rule-of-thumb, do not exceed the

³ Detailed calculations are outside the scope of this book, and can be found at the reference mentioned at the beginning of this manuscript.

100 runs for the standard simulation engine of the Time Shuttle since it requires a huge number of computations to guarantee that the scenario descriptions are followed. The advanced simulation engine used in the Sensitivity Scan is easier and more runs are possible within reasonable CPU time.

- * The simulation engine always generates earliest start schedules (ESS) for all project activities, even if you have shifted an activity later in time in the baseline schedule. If you want to avoid this and let your shifted activity start at your defined start date or later, add an activity constraint such as a ready time or locked time. Since the simulation engine always generates fictitious schedules using the forward constraint mode, an activity will never start earlier than its ready time, but sometimes later in case of delays in predecessor activities. More information on activity constraints can be found in the “Baseline Scheduling with ProTrack” chapter.

3 Simulation options

It has been mentioned earlier that the simulation engine can be launched by pressing **Project - New Simulation** which shows a sequence of screens that requires user inputs. The various inputs that can be chosen are briefly summarized along the following lines:

- Simulation type: Choice between a standard, advanced or random simulation.
- Sensitivity analysis: The user can choose to calculate the activity time, activity cost and/or resource cost sensitivity, or has to option to skip the calculation of these measures.
- EVM Analysis: Optional access to the Time Shuttle which allows the user to perform a project performance and forecast accuracy study using Earned Value Management as well as to generate automatic project tracking reports, as described in the “Project Control with ProTrack” chapter.
- Simulation with resources: The simulation engine can be used to measure sensitivity of a project schedule with or without the presence of renewable resources. Simulation without resources constructs a sequence of earliest start schedules where the limited availability of resources is completely ignored. Simulation with resources takes the resource constraints into account and leads to project schedules where the leveled resources are taken into account in two alternative ways:
 - Use current resource allocation: The current leveled project baseline schedule is used as input for the simulation. When changes in activity duration occur, it can create new resource conflicts which will not be resolved.
 - Full optimization of resources: The current leveled project baseline schedule is used as input for the simulation. Each time a project schedule is simulated, ProTrack tries to solve newly created resource over-allocations when possible.
- Summary screen: This screen gives a summary of the selected options and allows the user to modify the number of runs during the simulation.

Warning

- * Be aware that the choice of options influences your results. As an example, an EVM analysis for projects without cost information makes no sense or leads to very strange results. Moreover, a simulation with resources might lead to infeasible runs if over-allocations cannot be removed.
- * Schedule simulations with resources can lead to unrealistic sensitivity measures. As an example, the criticality index, which measures the likelihood that an activity lies on the critical path, is often meaningless within the presence of resources. Due to limited availability of resources and shifts in activity starting times to solve over-allocations, little or no activities lie on the critical path.
- * It is suggested to the user to fully explore all options before drawing any conclusions reported by ProTrack. Schedule risk analysis using project simulation is a very powerful but sometimes complex technique, which requires thorough understanding of the various input options and output measures.

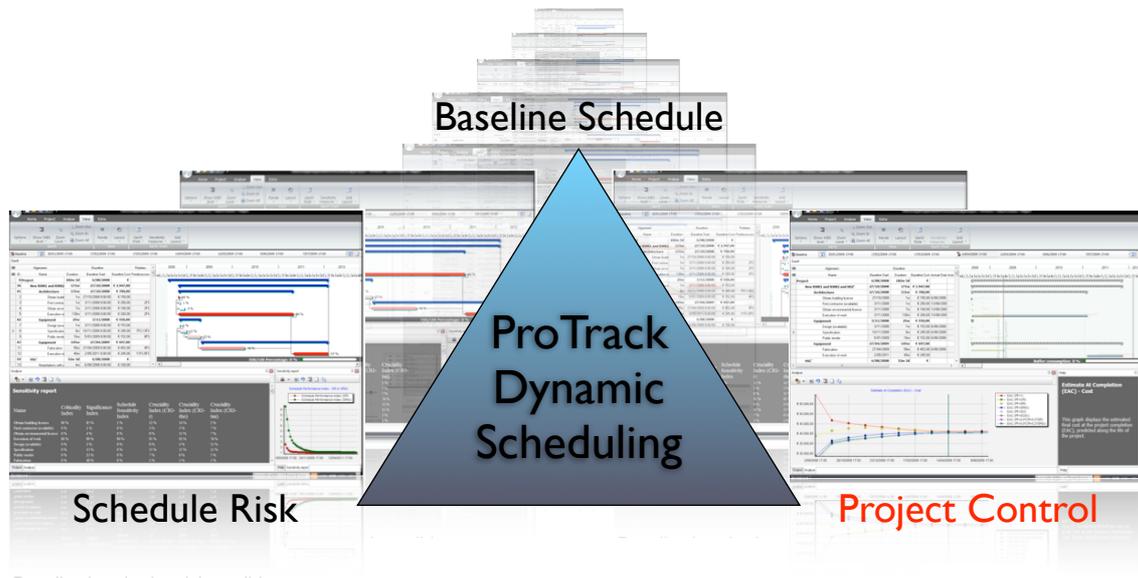
4 Conclusion

ProTrack's Sensitivity Scan allows you to easily set up a Schedule Risk Analysis to measure the sensitivity of individual project activities on the final duration of a project. It provides information of potential effects of risk on your project duration, and gives you an idea about the range of time between which your project will likely finish.

Although Schedule Risk Analysis is a technique that allows you to refine the traditional Critical Path Method (CPM) to degrees of criticality and risk, it also entails certain dangers. Results need to be interpreted to support your decision making process and need to be linked to your knowledge on risk and your project characteristics and environment. Do not use what you don't understand and cannot explain. Results need to be interpreted with care!

Note that Schedule Risk Analysis is not a goal in itself, but rather serves as a tool to improve and steer the project control phase. Indeed, the combination of the baseline schedule and the sensitivity information should be interpreted and used as a point-of-reference to reveal threats and opportunities during the project progress. More information on the baseline schedule and project control phases can be found in the "Baseline Scheduling with ProTrack" and "Project Control with ProTrack" chapters.

Chapter 4 Project Control with ProTrack



Project control (often referred to as project monitoring or project tracking) is the process performed to observe project execution in order to identify potential problems and/or opportunities in a timely manner such that corrective actions can be taken when necessary. The key benefit is that the current project status is observed on a regular basis, which enables the calculation of the project performance variance that is equal to the gap between actual performance and the baseline schedule. Since the current project performance is measured by variances from the project management plan, the baseline schedule plays a central and unambiguous role during the project tracking process.

ProTrack employs a strict definition of a unique baseline schedule for each tracking period, such that it is always clear during the complete project execution what the active baseline schedule is. ProTrack allows the user to define multiple tracking periods in order to get a clear view of the progress of the project over time. Each tracking period is linked to a unique status date and a corresponding baseline schedule, and measures the current progress up to the status date of the project compared to the active baseline schedule.

Note that the user needs to select a *single baseline schedule* for each tracking period. Consequently, this strict baseline schedule definition guarantees a clear and unambiguous interpretation of the current performance (i.e. the current performance compared to the active baseline schedule at the status date) and guarantees that only one baseline schedule is active at the same time.

Many project control features discussed in this chapter can be used in all ProTrack versions. However, some specialized features, such as the schedule adherence, forecast accuracy and automatic tracking features discussed later are specifically linked to the **Time Shuttle** option in ProTrack. The Time Shuttle option is available in two ProTrack versions: the Time Shuttle Version and the Smart Version.

1 Tracking periods

ProTrack's project tracking can be done by creating a new tracking period for each review period. These tracking periods appear as tabs above the tracking Gantt chart (see figure 4.1). Each tab is linked to a

unique status date and baseline schedule, and multiple tabs allow the user to get back in time and review previous tracking periods. It is therefore wise and necessary to create a new tab each time a new tracking update is done by the user.

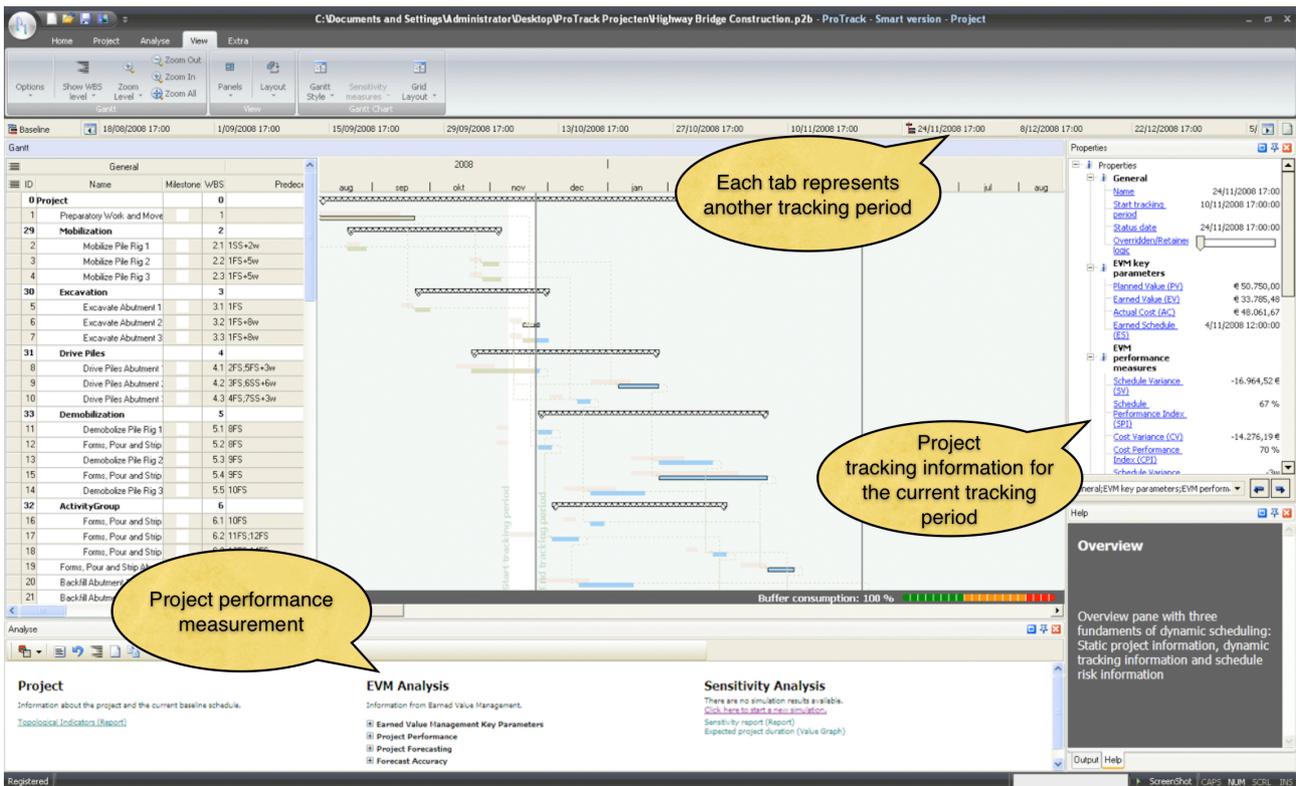


Figure 4.1. Tracking periods (tabs) in ProTrack

The creation of periodic tracking periods can be done through two manual interventions, as follows:

- **Save baseline schedule:** After the creation of the first tracking period tab, ProTrack assumes that your project has started. Consequently, the baseline schedule, which serves from this moment on as a point-of-reference for project control, cannot be changed anymore. Click on **Project - Save Baseline**.
- **Create new tracking period:** Each time a period is closed, the user can define a new project tracking period. In doing so, ProTrack allows the user to save intermediate tracking periods to see the evolution of the project progress over time. Click on **Project - Add Period**.

After saving the baseline, the user can periodically create tracking tab periods to enter updated information of the project progress. It is wise and necessary to create a new tracking period tab for each progress update. In doing so, the user can always go back in time to previous tabs to see the evolution of his/her project's progress. Moreover, all performance and earned value graphs (see section "3 EVM Analysis") will calculate progress information for each tab you create. Consequently, the more you periodically update your project's progress, the more data points and the more reliable your performance graphs will be.

Each tracking period is characterized by a start date and an end date. The start date is equal to the project start for the first tracking period or equal to the end date of the previous tracking period for all other project tracking periods. The end date, known as the status date (i.e. the day on which the project status has been finished) needs to be approximated at the creation of each tracking period, and needs to be changed and confirmed when finishing the tracking period (i.e. upon creation of a new tracking period). This simple method is outlined in figure 4.2.

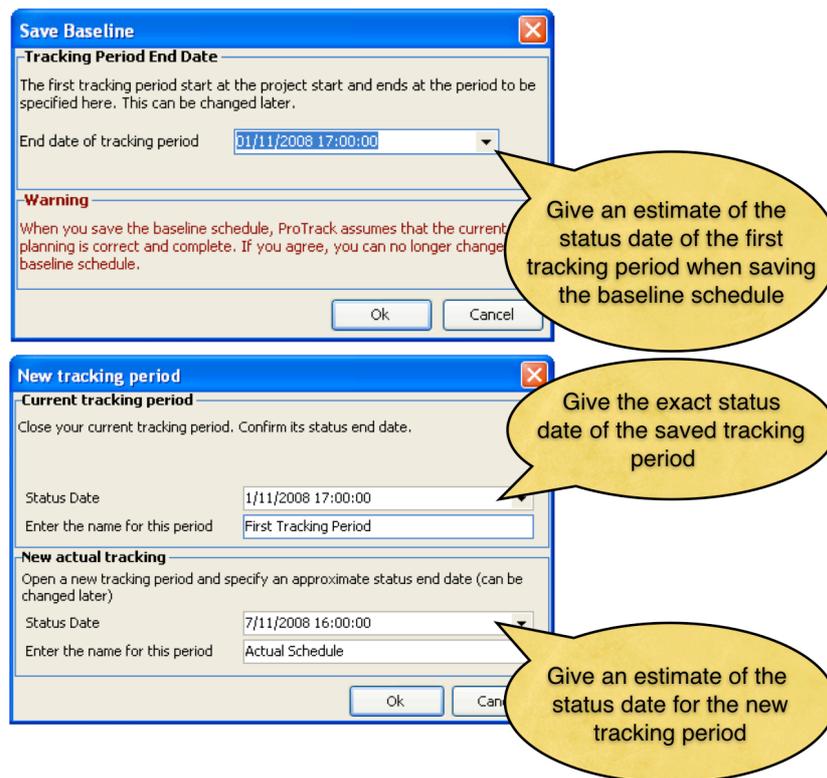


Figure 4.2. Setting the status date in ProTrack (saving the baseline schedule or creating a new tracking period)

Each project tracking period tab contains data about the progress of the project which will be used to update the tracking Gantt chart prediction (section 2) and to measure project performance and predict future project behavior using Earned Value Management (see section 3). Correct earned value based calculations depend on the quality and accuracy of the input parameters, which can be summarized along the following lines:

- **Actual Start:** Actual starting time of an activity on or before the status date which might differ from the original baseline start time.
- **Actual Duration (AD):** The time spent on an activity between its actual start time and the current status date. Hence, the actual duration can be smaller than, equal to or larger than the time span between the actual start and the current status date, and is used to represent the workload already spent on this activity until now.
- **Remaining Duration (RD):** A forecast of how many time units (hours, days, weeks, years) an activity will need from the status date forward to finish its remaining work.
- **Actual Cost (AC):** The actual cost for the work already done. Normally, this actual cost should have a clear relation with the workload already done by the various resources as given by the actual duration, but the user is free to adapt the actual cost to any monetary value. ProTrack has set up a unique way to enter actual and remaining cost data, using the following input parameters.
 - **Planned Actual Cost (PAC):** The planned actual cost is calculated automatically and cannot be changed by the user. This cost is based on the actual duration (AD) input and is calculated as the total resource cost for the activity when it has been in progress for AD time units. Consequently, the actual duration estimate given by the user to estimate the total workload spent on an activity determines the actual cost for this activity. For more information about resource costs, see the activity and resource cost section of the “Baseline Scheduling with ProTrack” chapter).
 - **Planned Actual Cost Deviation (PACDev):** However, since resources shift from time to time and work more or less efficient than originally planned, the *real* actual cost can differ from the theoretical actual cost where it is assumed that resources work as planned. Consequently, the

actual cost deviation is a way to express that difference, and hence, the total actual cost at a current moment in time is equal to:

$$\text{Actual Cost} = \text{Planned Actual Cost} + \text{Planned Actual Cost Deviation}$$

- **Remaining Cost (RC):** A forecast of how many additional monetary resources (euro, dollars, ...) an activity will need to finish the portion of remaining work. Similar to the actual cost estimate, the remaining cost estimate can be determined in the following way:
 - **Planned Remaining Cost (PRC):** The planned remaining cost is, similar to the planned actual cost, calculated automatically based on the remaining duration (RD) input.
 - **Planned Remaining Cost Deviation (PRCDev):** In order to give a realistic estimate of the remaining cost, the planned remaining cost value can be modified using the optional planned remaining cost deviation field. Consequently, the total remaining cost is calculated as follows:

$$\text{Remaining Cost} = \text{Planned Remaining Cost} + \text{Planned Remaining Cost Deviation}$$

- **Percentage Completed (PC):** The portion of the total workload that is estimated to be finished. The Earned Value metric EV is based on this estimate as $EV = PC * BAC$ (with BAC = Budget At Completion). Note that neither the actual/remaining duration nor the actual/remaining cost need to have a link with the PC estimate and will not be explicitly used for the calculation of the EV metric. More information is given in section 5.

Note that some of these project tracking key metrics can be calculated automatically using ProTrack's predefined EVM input models. These Project Tracking input models can be accessed from [Extra - Input Models](#), and will be discussed in section 5 "Advanced Options". The project tracking screen is given in figure 4.3.

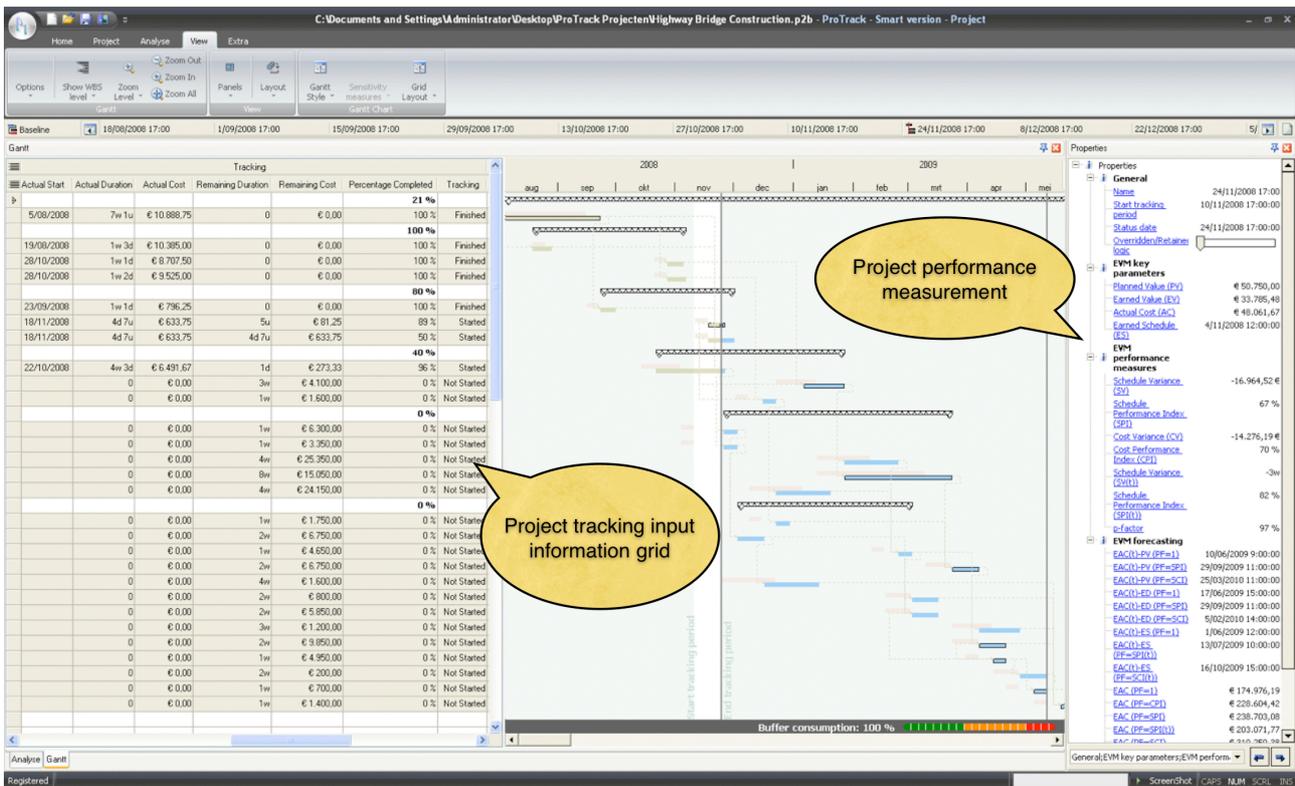


Figure 4.3. Tracking grid and tracking Gantt chart views

Note

- * You can easily switch between the baseline schedule data and the tracking period data by clicking on **View - Grid Layout**. The best view to monitor the progress of your project can be obtained at **View - Grid Layout - Default Tracking**.
- * Once project tracking has started, the baseline schedule can no longer be changed. Delete all tracking periods to change the baseline schedule again.

2 Schedule predictions

One of the primary tasks during project tracking is periodically updating the baseline schedule to reflect the actual progress of the work done and to present a realistic forecast of the remaining work. The tracking Gantt chart gives a prediction of the future schedule based on the inputs of actual and remaining durations/costs. However, it is important to realize that the schedule prediction of the tracking Gantt chart discussed here might differ from the schedule predictions using Earned Value Management (see the EAC(t) formulas of section 3). Both contain a schedule prediction but differ as follows:

- **Tracking Gantt chart prediction:** The schedule prediction displayed in the tracking Gantt chart displays the remaining project schedule, given the actual start dates of the started activities and their actual and remaining durations. The remaining duration of the un-started activities is equal to their baseline duration.
- **Earned Value Analysis prediction:** The schedule predictions using the EVM metrics of section 3 completely rely on the percentage completed (PC) estimates and their corresponding earned value metrics. Obviously, the PC estimate might completely differ from the actual and remaining duration estimates.

Since work is often performed *out-of-sequence*, the original logic captured by the precedence relations between activities as specified in the baseline schedule is often violated. This situation can cause unrealistic deviations between the baseline scheduling logic and the project tracking Gantt chart, and often leads to unnecessary adaptations and modifications to the baseline schedule. ProTrack has two options to handle out-of-sequence progress during the tracking phase, as follows:

- **Retained logic** assumes that the original precedence relations are still valid, even when activity overlaps during progress have taken place. This logic respects all precedence relations of the remaining work, but often leads to unrealistic long project duration forecasts.
- **Overridden logic** assumes that an activity that started with a certain overlap will violate the original precedence relation logic completely. This logic assumes that the remaining work of an activity in progress can be done without being affected by its incomplete predecessor activities, but it often leads to unrealistic short project duration forecasts. This logic is also known as out-of-sequence progress.

While the option between the retained and overridden logic is standard in most commercial software tools, ProTrack has extended this option to all possibilities in between these two extremes:

- **Overridden/Retained logic percentage:** Since both the overridden and the retained logic display a schedule forecast taking both the actual activity durations (the work done) and the remaining activity durations (the work yet to be done) into account, ProTrack has the option to construct a schedule forecast for the remaining work yet to be done in between the overridden and retained logic. Motivated by the observation that the Gantt chart of the remaining work is nothing more than a schedule forecast, the option to shift between the two extreme logics allows the user to fine-tune the forecast according to his/her own wishes. A simple slider, similar to the ESS/LSS slider (see the “Project Baseline with ProTrack” chapter), gradually shifts the tracking Gantt chart from an overridden logic to a retained logic situation. This overridden/retained logic slider plays an important role in the buffer management approach set during the scheduling phase. During the project scheduling phase, a buffer is set as a well-considered choice of a certain degree of safety time on top of the project duration. This buffer acts as a simple project tracking dashboard, since project tracking leads to possible buffer consumption and hence visualizes the likelihood of violating the predefined deadline. The options between the overridden and retained logic obviously affects the buffer consumption and can be used to predict and influence the estimated project finish. Figure 4.4 shows the overridden/retained logic screen in ProTrack.

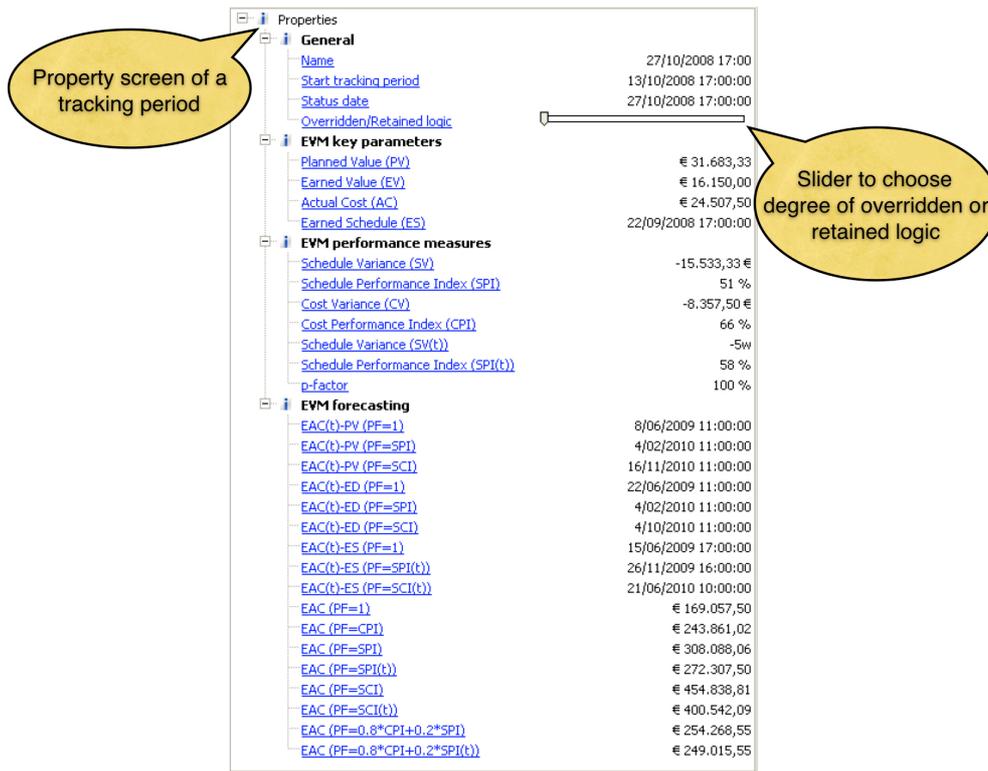


Figure 4.4. Retained versus Overridden logic in ProTrack

Note

- ProTrack offers two alternative views on the project progress Gantt chart. The default view can be shown via the **View - Gantt Style - Tracking View** menu and shows two Gantt charts in one screen. The progress Gantt chart shows the progress of the activities that are completed or in progress and shows a prediction of future work as discussed in this section. Moreover, this view also shows the original baseline schedule (displayed in light at the background) for comparison purposes. Alternatively, the **View - Gantt Style - Baseline ES View** menu transforms the progress data into a single Gantt chart and shows the time progress relative to the baseline schedule. This view serves as an ideal tool to monitor your time progress relative to the baseline schedule, as measured by the Earned Schedule (ES) metric as discussed in section 3. This Gantt chart view is discussed in the 'schedule adherence' topic of section 3.2.

3 EVM Analysis

Earned Value Management (EVM) systems have been set up to deal with the complex task of controlling and adjusting the baseline project schedule during execution, taking into account project scope, timed delivery and total project budget. It is a well-known and generally accepted management system that integrates cost, schedule and technical performance and allows the calculation of cost and schedule variances and performance indices and forecasts of project cost and schedule duration. The earned value method provides early indications of project performance to highlight the need for eventual corrective actions.

The ProTrack tracking options mainly follow the standard EVM principles and techniques described in numerous references. Many of the ProTrack EVM features have been implemented in most standard software tools, but others are completely new and rely on the results of a large Earned Value simulation study. The main EVM features are briefly summarized along the following lines:

- **Earned Value Management:** Automatic calculation of the standard EVM key metrics and extensions to earned schedule project tracking and performance measurement.
- **Schedule adherence:** Automatic calculation of the p-factor to dynamically measure schedule adherence.
- **Time/Cost forecasting:** EVM forecasting based on the three methods presented throughout literature.
- **Forecast accuracy:** ProTrack is an ideal EVM learning tool and contains simulation engines to simulate fictive project progress to measure the accuracy of time and cost forecasts.
- **Gantt chart tracking:** A choice between retained logic and overridden logic (all intermediate levels inclusive) to predict the remaining work shown in a tracking Gantt chart (see section 2). This Gantt chart can replace the current baseline schedule (i.e. re-baselining) when necessary.
- **Reporting:** A wide range of flexible reports customized with various logos can be easily made.

Table 4.1 summarizes the EVM measures used in ProTrack, classified in the Earned Value Management Key Parameters, the metrics to measure the Project Performance, the Project Forecasting techniques (both for time and cost) and the Forecast Accuracy metrics to measure the quality of the forecasts. These four EVM classes are discussed along the following subsections. All measures are available via the [Analyse - Overview](#) menu.

Table 4.1. EVM measures used in ProTrack

| Graph name | Meaning |
|---|--|
| Earned Value Management Key Parameters | |
| S-curve | This graph displays the Planned Value (PV), the Actual Cost (AC) and Earned Value (EV) along the life of the project. |
| PV curve | This graph displays the Planned Value (PV) as shown in the S-curve. Since the Planned Value curve is available at the construction of the baseline schedule (before the EVM tracking), this graph is accessible separately from the S-curve. |
| Quick EVM overview | Gives all performance measurement information. |
| Earned Schedule (ES) | This graph displays the Earned Schedule (ES) calculated from the Earned Value and Planned Value graph along the life of the project. |
| Project Performance | |
| EVM Performance Dashboard | This graph displays both the time and cost performance and divides the project performance into four regions showing time and cost performance. |
| Cost Variance (CV) | This graph displays the Cost Variance ($CV = AC - EV$) along the life of the project. |
| Cost Performance (CPI) | This graph displays the Cost Performance Index ($CPI = AC / EV$) along the life of the project. |
| Schedule Variance (SV and SV(t)) | This graph displays the Schedule Variance (SV or SV(t)) along the life of the project. Formulas used: $SV = PV - EV$ and $SV(t) = ES - AT$. |
| Schedule Performance (SPI and SPI(t)) | This graph displays the Schedule Performance Index (SPI or SPI(t)) along the life of the project. Formulas used: $SPI = EV / PV$ and $SPI(t) = ES / AT$. |

| Graph name | Meaning |
|--------------------------------------|--|
| Schedule Adherence (p-factor) | This graph displays how good the project progress follows the baseline schedule philosophy. This is known as schedule adherence and measured by the p-factor. Tip: p-factor = % schedule adherence (100% = perfect adherence). |
| Project Forecasting | |
| Cost Estimate At Completion (EAC) | This graph displays the estimated final cost at the project completion (EAC) predicted along the life of the project. Eight forecasting versions are used, in line with research from literature. |
| Time Estimate At Completion (EAC(t)) | This graph displays the estimated final duration at the project completion (EAC(t)) predicted along the life of the project. Three methods are used (PVM, EDM and ESM), each using three variants (see table 4.2). |
| EAC(t) report | This report shows a summary of the nine time forecasting methods (EAC(t)) at a certain point during the progress of the project. |
| Forecast Accuracy | |
| MAPE | This graph displays the Mean Absolute Percentage Error as a measure of the forecast accuracy of time predictions. |
| MPE | This graph displays the Mean Percentage Error as a measure of the forecast accuracy of time predictions. |

3.1 Key Parameters

EVM relies on three key parameters which can be shown in one graph, known as the *S-curve*. These three parameters are:

- The **Planned Value (PV)**: Time-phased budget baseline as an immediate result of the baseline schedule, often called the Budgeted Cost of Work Scheduled (BCWS).
- The **Actual Cost (AC)**: The cumulative actual cost spent at a given status date, often referred to as the Actual Cost of Work Performed (ACWP).
- The **Earned Value (EV)**: Represents the amount budgeted for performing the work that was accomplished by a given status date, often called the Budgeted Cost of Work Performed (BCWP) and equals the total activity (or project) budget at completion multiplied by the percentage activity (or project) completion (PC) at this particular point in time ($= PC * BAC$).

ProTrack incorporates a fourth EVM metric derived from the PV and EV metrics, known as the Earned Schedule metric, as follows:

- The **Earned Schedule (ES)**: Translation of the EV of a given status date into time units by determining when this EV should have been earned in the baseline schedule.

Consequently, the Earned Schedule metric measures your project progress in a time dimension and varies between 0 time units (at the start of the project) and the baseline Planned Duration (PD) at the end of the project. Hence, at the end of the project, $EV = PV$ and $ES = PD$.

The AC, EV and ES metrics are gradually built up by adding tracking periods and updating project progress over time. The PV metric, however, is built during the baseline scheduling phase, and is therefore accessible via a separate graph under the [Analyse - Show Graph - EVM Key Parameters - PV Curve](#) menu.

These EVM metrics can be summarized in the Quick EVM overview or can be displayed through various graphs, as shown in figure 4.5.



Figure 4.5. EVM key parameters in ProTrack

Note

- * The Planned Value graph can be graphically displayed and changed by making changes at the baseline schedule. Easy and quick modifications can be done by shifting between an Earliest Start Schedule (ESS) and a Latest Start Schedule (LSS) (see baseline property screen) which allows you to investigate your cash outflow position under different baseline scenarios. More information can be obtained from the “Baseline Scheduling with ProTrack” chapter.
- * A more detailed graph view can be obtained by marking a part of the graph with the mouse from the left upper corner to the right bottom corner.

3.2 Performance measurement

Project performance, both in terms of time and costs, is determined by comparing the key parameters PV, AC, EV and ES, resulting in four well-known performance measures.

- **Cost Variance (CV):** Shows the variance in cost ($AC - EV$) expressed in monetary terms
 - > 0: over budget
 - = 0: on budget
 - < 0: under budget
- **Schedule Variance (SV):** Shows the variance in time ($PV - EV$) expressed in monetary terms
 - > 0: project ahead of schedule
 - = 0: project on time
 - < 0: project delay

- **Cost Performance Index (CPI):** Shows the performance of cost (AC / EV) in a unit-less dimension
 - > 100%: over budget
 - = 100%: on budget
 - < 100%: under budget
- **Schedule Performance Index (SPI):** Shows the performance of time (PC / EV) in a unit-less dimension
 - > 100%: project ahead of schedule
 - = 100%: project on time
 - < 100%: project delay

Since the Earned Value metric EV is always equal to the Planned Value metric PV at the end of the project, the SPI always ends at 100%, regardless of the real project state (early, on time or late). This unreliable trend of the SPI has been the topic of many discussions and research projects⁴, which has eventually resulted in two new time measures, similar to the SV and SPI, as follows:

- **Schedule Variance (SV(t)):** Shows the variance in time (ES - AT) expressed in monetary terms
 - > 0: project ahead of schedule
 - = 0: project on time
 - < 0: project delay
- **Schedule Performance Index (SPI(t)):** Shows the performance of time (ES / AT) in a unit-less dimension
 - > 100%: project ahead of schedule
 - = 100%: project on time
 - < 100%: project delay

with AT = the current Actual Time, which is given by the *status date* of the tracking period tab. Example graphs are given in figure 4.6.

⁴ See the articles by Lipke (Schedule is different. The Measurable News, Summer:31-34, 2003) and by Vandevoorde and Vanhoucke (A comparison of different project duration forecasting methods using earned value metrics. International Journal of Project Management, 24:289-302, 2006).

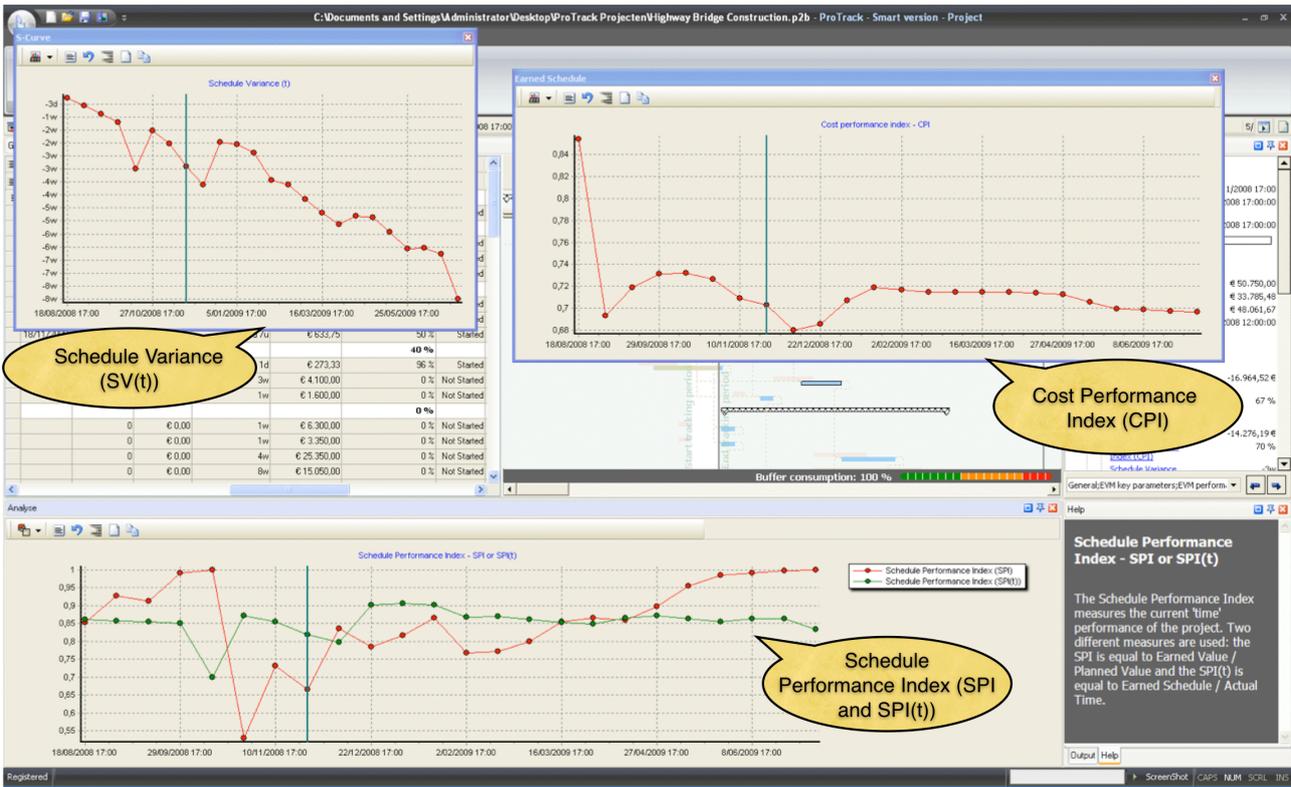


Figure 4.6. Project performance measurement (time and cost) in ProTrack

Time and cost performance can be shown in a single graph using the **Analyse - Show Graph - EVM Performance Measures - EVM Dashboard** menu (figure 4.7). The dashboard displays the CPI and SPI(t) evolution for the different tracking periods.

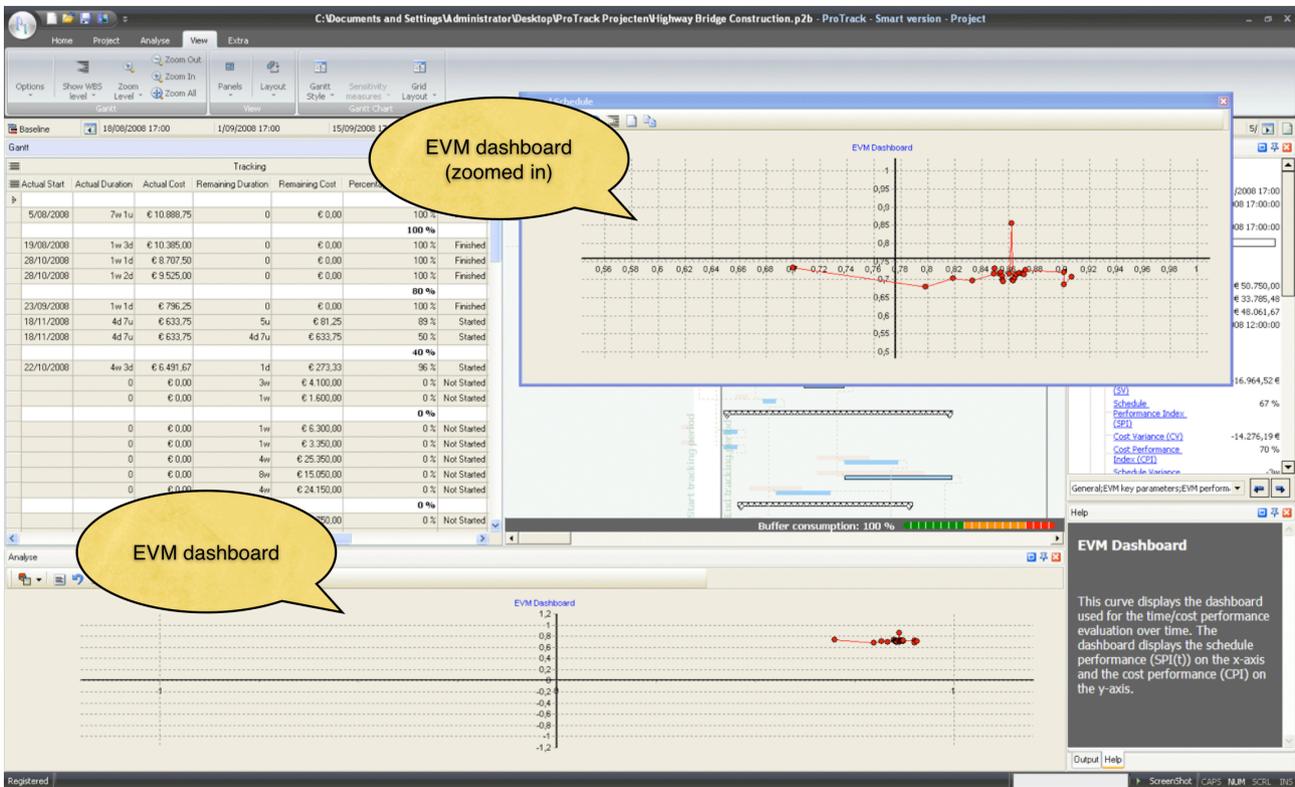


Figure 4.7. EVM dashboard in ProTrack

ProTrack’s performance measurement contains a new EVM concept, known as Schedule adherence⁵, which completely relies on the ES definition. It is measured by the p-factor metric and makes the connection of project output to EVM, as follows:

- **Schedule adherence (p-factor):** Ratio of the Earned Value corresponding to the baseline schedule at time period ES divided by the total planned value at time period ES.

The p-factor measures adherence to the baseline schedule relative to the current time performance measured by the ES. It shows to what degree the baseline schedule logic is followed at the time period measured by the ES metric. More precisely, it is equal to the ratio of the Earned Value corresponding to the baseline schedule (i.e. if the current activity EV exceeds the activity PV at the time period ES, the EV is limited to the corresponding PV at time ES) divided by the total planned value at time instance ES. Since the nominator takes the minimum of the planned value at time unit ES and the earned value accrued at the actual time, the p-factor obviously always lies between zero and one, inclusive. Hence, the p-factor measures to what degree the earned value is accrued according to the baseline schedule (100% means a perfect schedule adherence).

The alternative tracking Gantt chart view can be shown by clicking on the **View - Gantt Chart - Baseline ES view** menu (figure 4.8). It shows the difference between the status date and the Earned Schedule metric (i.e. the SV(t)) and reveals that the project is behind (ES < Status Date) or ahead (ES > Status Date) of schedule, as well as the adherence of the current work done relative to the ES metric. The black bars show the EV accrue for the individual activities, which can lie to the left or to the right of the ES line. The p-factor is equal to the portion of earned value accrued in congruence with the baseline schedule, i.e. the tasks which ought to be either completed or in progress. A perfect (i.e. 100%) schedule adherence should show a Gantt chart where the EV accrue ends at or exceeds the ES line for all project activities.

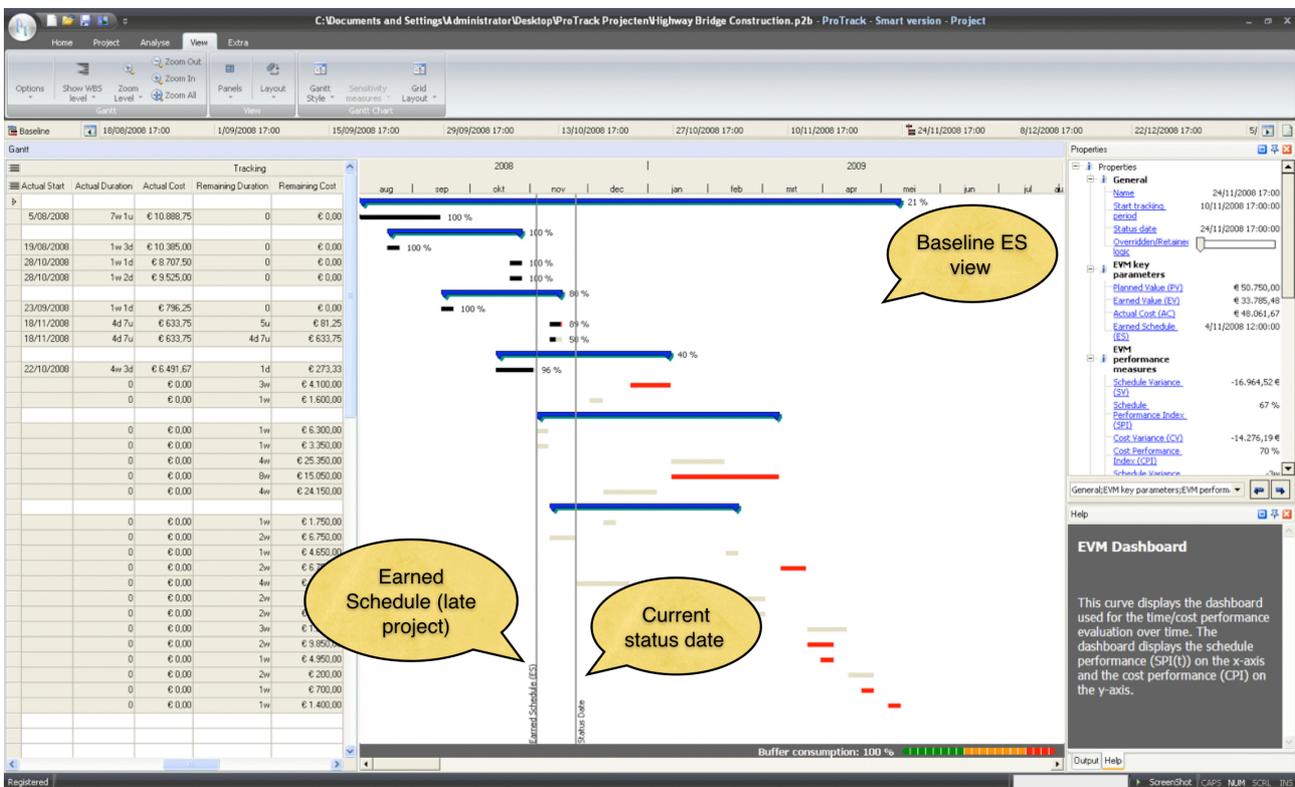


Figure 4.8. Baseline Earned Schedule view

⁵ Based on an article written by Lipke (Connecting earned value to the schedule. The Measurable News. Winter:1, 6–16, 2004).

3.3 Predictions

EVM uses the current project performance, measured by the SPI and SPI(t) metrics for time and the CPI for cost, to predict the final duration and cost of a project. The general abbreviations to forecast time and cost in ProTrack are as follows:

- Expected At Completion - Cost (EAC): Forecast of total project cost at the current status date, which might be different from the original budget or Budget At Completion (BAC).
- Expected At Completion - Time (EAC(t)): Forecast of final project duration at the current status date, which might differ from the baseline Planned Duration (PD).

All EAC and EAC(t) predictions can be shown on graphs or a report for each tracking period can be generated via the **Analyse - Show Graph - EVM Forecasting** menu (see figure 4.9).



Figure 4.9. Time and cost predictions in ProTrack

3.3.1 Time forecasting EAC(t)

Predicting the final duration of the project during its progress is one of the main targets of EVM. ProTrack relies on 3 forecasting methods, and each method can be used under 3 versions (see table 4.2). Each version relies on another performance factor (PF) which refers to the assumption about the expected performance of the future work, as follows:

- PF = 1: Future performance is expected to follow the baseline schedule.
- PF = SPI or SPI(t): Future performance is expected to follow the current time performance.

- PF = SCI or SCI(t)⁶: Future performance is expected to follow the current time and cost performance.

All these methods provide an estimate for the total project duration, and offer a range of possibilities and hence a lower and upper bound on your predicted total time. The choice of a specific forecasting method depends on the project, your expertise and many other unknown factors. Information on the quality of the EAC(t) forecasts can be found in literature⁷ or can be obtained by using the Time Shuttle option as discussed in section 4.

Table 4.2. Time predictions in ProTrack

| Forecasting method | Version 1: according to plan | Version 2: according to current time performance | Version 3: according to current time/cost performance |
|------------------------------|------------------------------|--|---|
| Planned Value Method (PVM) | $EAC(t)_{PV}$ (PF = 1) | $EAC(t)_{PV}$ (PF = SPI) | $EAC(t)_{PV}$ (PF = SCI) |
| Earned Duration Method (EDM) | $EAC(t)_{ED}$ (PF = 1) | $EAC(t)_{ED}$ (PF = SPI) | $EAC(t)_{ED}$ (PF = SCI) |
| Earned Schedule Method (ESM) | $EAC(t)_{ES}$ (PF = 1) | $EAC(t)_{ES}$ (PF = SPI(t)) | $EAC(t)_{ES}$ (PF = SCI(t)) |

3.3.2 Cost forecasting EAC

Predicting the final cost of the project during its progress can be easily done in ProTrack using four main predefined methods. Most of these methods have been validated in literature, and are summarized in table 4.3. Each method relies on another performance factor (PF) which refers to the assumption about the expected performance of the future work, as follows:

- PF = 1: Future performance is expected to follow the baseline schedule (version 1).
- PF = SPI or SPI(t): Future performance is expected to follow the current time performance (version 2).
- PF = CPI: Future performance is expected to follow the current cost performance (version 3).
- PF = SCI or SCI(t): Future performance is expected to follow the current time and cost performance. This method can be used under two versions, i.e. PF is equal to the current SCI performance (version 4) or to a weighted time and cost performance (version 4').

Note that versions 3, 4 and 4' can be used under the traditional Schedule Performance Index (SPI) assumptions, or with the new Earned Schedule based Schedule Performance Index (SPI(t)). All these methods provide an estimate for the total predicted cost at the end of the project, and offer a range of possibilities and hence a lower and upper bound on what you can expect to spend on your project. The choice of a specific forecasting method depends on the project, your expertise and many other often unknown factors.

⁶ SCI = Schedule Cost Index (SCI = SPI * CPI and SCI(t) = SPI(t) * CPI)

⁷ See the article by Vanhoucke and Vandevoorde (A simulation and evaluation of earned value metrics to forecast the project duration, Journal of the Operational Research Society, 58, 1361–1374, 2006).

Table 4.3. Cost predictions in ProTrack

| | Version 1: according to plan | Version 2: according to current cost performance | Version 3: according to current time performance | Version 4: according to current time/cost performance | Version 4': according to weighted time/cost performance |
|--------|---|---|---|--|--|
| SPI | EAC (PF = 1) | EAC (PF = CPI) | EAC (PF = SPI) | EAC (PF = SCI) | EAC (PF = 0.8*CPI + 0.2 SPI) |
| SPI(t) | | | EAC (PF = SPI(t)) | EAC (PF = SCI(t)) | EAC (PF = 0.8*CPI + 0.2 SPI(t)) |

3.4 Forecast accuracy

Predicting the total time and cost of a project using the different EAC and EAC(t) formulas might be subject to errors, and the quality of the predictions depends on many factors (quality of input data, characteristics of the project, etc.). The study “Measuring Time - An Earned Value Simulation Study” has measured the quality of time predictions, known as the forecast accuracy, using an extensive simulation study. The study has been awarded by the Belgian chapter of the Project Management Institute (the research collaboration fund of PMI Belgium⁸) and the International Project Management Association (the IPMA 2008 research award⁹).

ProTrack has built a **Time Shuttle** option (see next section) to incorporate the research simulation study by connecting the two simulation engines (the standard and advanced simulation engines as discussed in the “Schedule Risk Analysis with ProTrack” chapter) with the EVM analysis tool discussed here. The forecast accuracy is measured by the difference between all predictions along the project progress (the EAC(t) formulas) and the final real project duration, and reports two accuracy measures:

- Mean Absolute Percentage Error (MAPE): Average absolute deviation between all EAC(t) forecasts and the final project duration (lower values denote higher forecast accuracy).
- Mean Percentage Error (MPE): Average deviation between all EAC(t) forecasts and the final project duration (negative values denote average underestimates and positive values denote average overestimates).

The forecast accuracy study allows the user to measure how accurate the different EAC(t) project duration forecasts will be for their specific project under different controlled circumstances. In this respect, ProTrack serves as an ideal learning tool for practitioners and academics to learn how EVM predictions vary under specific project circumstances. The MAPE and MPE results are illustrated in figure 4.10.

⁸ See the PMI Research Collaboration Fund (2007) at www.pmi-belgium.be

⁹ See the IPMA Research Awards (2008) at www.ipma.ch

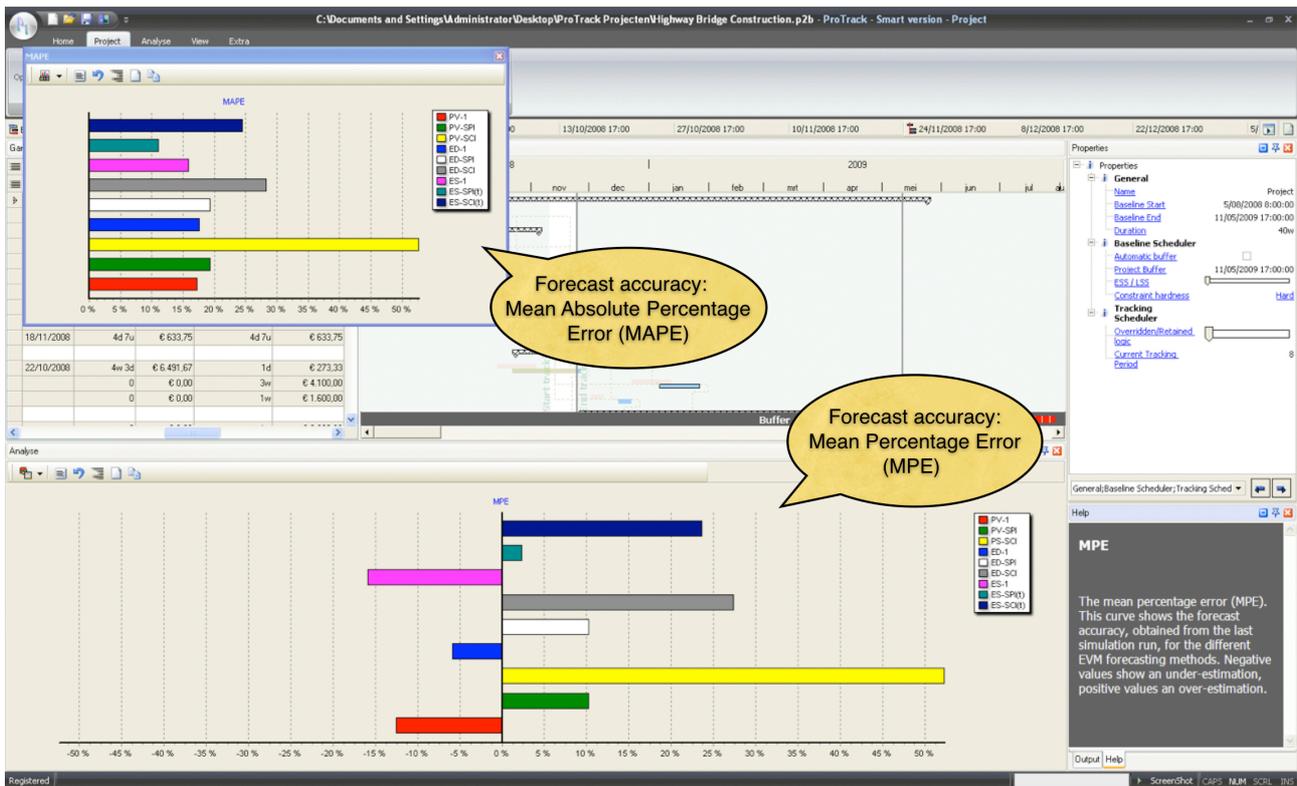


Figure 4.10. Time forecast accuracy results in ProTrack

The Time Shuttle option integrates Schedule Risk Analysis (see the “Schedule Risk Analysis with ProTrack” chapter) with Earned Value Management (this chapter), and is discussed in the next section.

4 Time Shuttle

ProTrack’s Time Shuttle allows the user to perform a project performance and forecast accuracy study using Earned Value Management as well as generate automatic project tracking reports. The Time Shuttle can be accessed by means of the two simulation engines incorporated in the simulation screen of ProTrack. Both engines serve different needs, and can be accessed by a simple click on **Project - New Simulation - Simulation Type**. Details and specific features of both engines are described in the “Schedule Risk Analysis with ProTrack” chapter.

- **Standard simulation engine:** Allows the user to start a quick and easy simulation tool without a thorough study of the risk profiles of the various project activities.
- **Advanced simulation engine:** Requires a more detailed risk quantification for each project activity, and constitutes the heart of the schedule risk analysis in ProTrack.

The Time Shuttle option connects the two simulation engines with the tracking periods of the project control phase, and can be used for two purposes:

- **Forecast accuracy study:** The Time Shuttle option allows to replicate simulation studies for specific projects to measure the quality of the time predictions using the nine EAC(t) formulas by reporting the MAPE and MPE as discussed earlier (see section 4.1).
- **Automatic tracking:** Creation of automatic fictive tracking periods to create artificial project progress and fictive EVM graphs and reports that serve as a learning tool for your project (see section 4.2).

Table 4.4 displays a summary showing the two different simulation engines and their relation to the Sensitivity Scan and the Time Shuttle option. In the next subsections, only the Time Shuttle option is discussed.

Table 4.4. The relation between ProTrack’s simulation engines and its Sensitivity Scan and Time Shuttle options

| | Sensitivity Scan | Time Shuttle |
|---------------------|---|---|
| Standard Simulation | Use one of the 9 predefined simulation scenarios in order to scan the sensitivity of all project activities (Time Shuttle option will be automatically on). | Use one of the 9 predefined simulation scenarios in order to measure the EAC(t) forecast accuracy or to generate automatic tracking periods. |
| Advanced Simulation | Use the distribution drawer to define activity duration uncertainty in order to scan the sensitivity of all project activities. | Use the distribution drawer to define activity duration uncertainty in order to measure the EAC(t) forecast accuracy or to generate automatic tracking periods. |
| | See the “Schedule Risk Analysis with ProTrack” chapter. | See the “Project Control with ProTrack” chapter. |

4.1 Forecast accuracy

A forecast accuracy study makes use of the simulation engines that are accessible by clicking on **Project - New Simulation - Simulation Type**. The properties screen lets you choose between the **Standard Simulation** or **Advanced Simulation** engines, as explained in the “Schedule Risk Analysis with ProTrack” chapter.

The forecast accuracy calculations can be called by putting the **9 Standard (EVM) scenarios (= Time Shuttle)** option on. ProTrack will lead you through a sequence of self-explanatory screens, with the “EVM Analysis” screen displaying the settings of the properties of the time shuttle to start a EVM forecast accuracy simulation.

The properties screen contains three Time Shuttle settings as follows:

- Tracking Interval: Defines the number of tracking periods for each individual project simulation run.
- % Completion Start: Defines the starting point to track your project expressed as a percentage completed ($PC = EV / BAC$). The default start is set at 0%, which denotes that all EVM calculations start at the beginning of the project.
- % Completion Finish: Defines the starting point to track your project expressed as a percentage completed ($PC = EV / BAC$). The default start is set at 100%, which denotes that all EVM calculations finish at the completion of the project.
- Accrue type: This setting determines how the EV accrue is simulated during fictitious project progress:
 - Linear accrue: refers to an accrue which is similar to the PV accrue in the baseline schedule. The activity may be longer or shorter than its baseline version, but the EV accrue follows a similar linear pattern than its baseline version.
 - Concave or convex: The EV is accrued faster (concave) or slower (convex) than originally planned, denoting that resources are allocated earlier or later to the activity than originally planned.

At the end of the screen sequence, the user gets an overview of the various choices he/she has made. The user can change the **Number of Runs** from 100 (default) to another value and start the simulation runs.

Note

- * Beware of changing the number of simulation runs to high values. The simulation engines of the Time Shuttle repetitively simulate project progress by creating tracking periods and calculating all EVM metrics to measure the quality of the EAC(t) predictions under controlled simulation scenarios. Consequently, the time shuttle requires extensive computations which can lead to a high CPU time.
- * Beware of small Time Shuttle tracking intervals. The interval between tracking periods determines the total number of tracking periods per simulation run and consequently influences the computational burden of the Time Shuttle. As a general rule of thumb, it is wise to follow the suggestion proposed by ProTrack to keep the number of tracking periods to a reasonable number.
- * The interval between % Completion Finish - % Completion Start is by default 100%, which denotes that the EVM metrics are calculated along the whole project progress. It is, however, possible to reduce that interval to smaller time windows, to measure the accuracy at certain time regions of the project life. Beware that the interval can be decreased in such a way that it contains no observations. In this case, the forecast accuracy variables MAPE and MPE will be misleading or will simply not exist.

4.2 Automatic tracking

The Time Shuttle can be used to create automatic tracking periods that allow the user to learn how the tracking input and EVM outputs work and interact for a specific project example. Since ProTrack’s project tracking approach relies on EVM, the automatic tracking period option only works with the standard simulation engine that allows a choice between 9 simulation scenarios using the SPI(t) indicator (alternatively, the quick and easy random simulation engine can be used). Details and specific features of the standard simulation engine are discussed in the “Schedule Risk Analysis with ProTrack” chapter.

The automatic tracking option can be accessed via the **Project - Simulate Tracking** menu that displays the standard simulation engine with the 9 simulation scenarios (see figure 4.11).

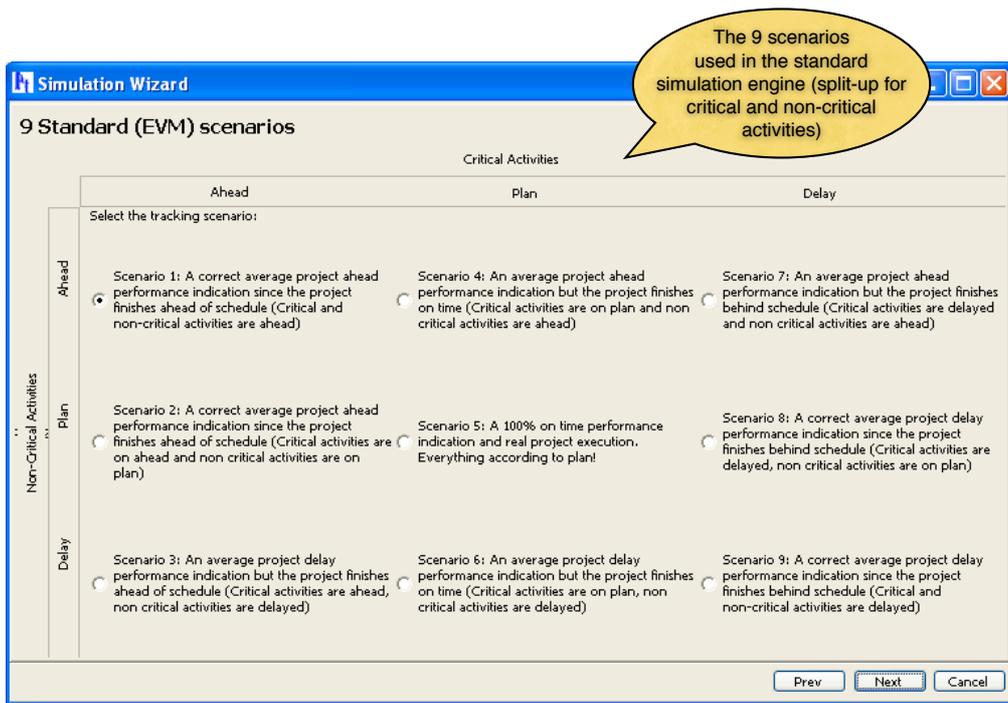


Figure 4.11. Automatic project tracking: the standard simulation engine screen

5 Advanced options

Project tracking can be a time intensive task when every activity needs a periodic update. Moreover, the EVM calculations rest on a number of assumptions which need to be followed to make the EVM output understandable and relevant. ProTrack has incorporated a number of EVM input models to assure that most assumptions are automatically checked and to facilitate the manual input for the user.

The EVM input models are optional and can be accessed via the [Extra - Input Models](#) menu. ProTrack contains five input models that can be optionally selected to support and facilitate the project tracking phase.

- **EVM Validation Model:** This validation model contains general tracking rules that need to be followed in order to assure that the EVM interpretations make sense.
 - Since EVM relies on baseline cost information, a tracking generation for a project without baseline cost information is invalid.
- **Initialize Actual/Remaining Duration:** When the Actual Start for an activity is entered, ProTrack automatically calculates the Actual and Remaining Durations given the status date of the tracking period and the baseline duration as follows:
 - Actual Duration = $\text{MIN}(\text{Status Date} - \text{Actual Start}, \text{Baseline Duration})$
 - Remaining Duration = $\text{Baseline Duration} - \text{Actual Duration}$
- **Percentage Completion According to Duration:** The Percentage Completion (PC) is a crucial estimate that determines the Earned Value EV. Although this value can differ from the actual and remaining activity duration, this EVM input model allows automatic PC calculations based on Actual and Remaining Duration estimates, as follows:
 - $\text{PC} = \max(\text{PC}_{\text{previous period}}, \text{Actual Duration} / (\text{Actual Duration} + \text{Remaining Duration}))$
- **Percentage Completion According to Cost:** Similar to the previous EVM input model, a similar EVM input model allows automatic PC calculations based on Actual and Remaining Cost estimates, as follows:
 - $\text{PC} = \max(\text{PC}_{\text{previous period}}, \text{Actual Cost} / (\text{Actual Cost} + \text{Remaining Cost}))$

Obviously, all automatic ProTrack calculations are only performed to speed up the tracking input effort and can be changed at all times during the project tracking period. All the underlying assumptions of the EVM input models that have been switched on are automatically checked when closing a tracking period (to open a new tracking period or to finish the project). If violations against the assumptions occur, ProTrack will report a warning and allow the user to change the inputs before continuing. However, the user can also perform an intermediate feasibility check with closing the tracking period check via the [Project - Check Tracking Period](#) menu.

6 Conclusion

Project tracking and control constitute the heart of any scheduling tool and play a central role in all ProTrack versions. They all combine Gantt chart schedule forecasts and Earned Value Management performance measurements to control the progress of your project and to make accurate predictions about the future. All versions make use of the new Earned Schedule approach to measure the time performance of your project in a reliable way.

ProTrack's Time Shuttle version allows you to create schedule adherence information, to easily set up a forecast accuracy study and to automatically create project tracking periods. It connects the standard

simulation engine of ProTrack's Sensitivity Scan with a time forecasting study and allows the users to obtain information about the quality of the various time predictions for their specific project.

Note that project tracking and control relies on the baseline schedule data. Ideally, a project tracking approach should use all relevant information that project managers have obtained during the planning phase, and should rely on data from the baseline scheduling step as well as information from the schedule risk analysis phase. More information can be found in the "Baseline Scheduling with ProTrack" and "Schedule Risk Analysis with ProTrack" chapters.



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