Chapter 15
Dynamic Scheduling with ProTrack

15.1 Introduction

ProTrack (acronym for *Pro*ject *Track*ing) is a project scheduling and tracking software tool developed by OR-AS[1] to offer a straightforward yet effective alternative to the numerous project scheduling and tracking software tools. The software has been built based on the results of the research studies discussed in Vanhoucke (2010a) and the many discussions with practitioners using software tools for dynamic scheduling. The project scheduling, risk analysis and project control approach is based on the current best practices from literature. ProTrack has been developed based on many research projects on the three dimensions of dynamic scheduling. Moreover, ProTrack also contains three additional engines based on state-of-the-art research in dynamic scheduling: a project generation engine, a simulation engine and a time forecasting engine. Each of these engines will be discussed in the current chapter.

Figure 15.1 shows the three dimensions of dynamic scheduling in ProTrack and is taken from the ProTrack website www.protrack.be. This chapter briefly highlights the main characteristics of ProTrack that are novel compared to traditional project management software tools and presents an overview of the features discussed throughout the various chapters in this book. More detailed information about the specific features of ProTrack, as well as tutorials to set up a dynamic schedule can be freely downloaded from the ProTrack website.

ProTrack has been released at the end of 2008 under four different versions as a critical path scheduler using earned value management to control the project progress. The second major version (ProTrack 2.0) has been released on February 2010 incorporating the option of scheduling renewable resources using basic functionalities of Chap. 7 in each of the four versions. The third major version

[1]OR-AS is a company founded in 2007 in order to bring principles and methodologies from the *O*perations *R*esearch discipline to a practical environment through software *A*pplications and/or consultancy *S*olutions. For more information, visit www.or-as.be.

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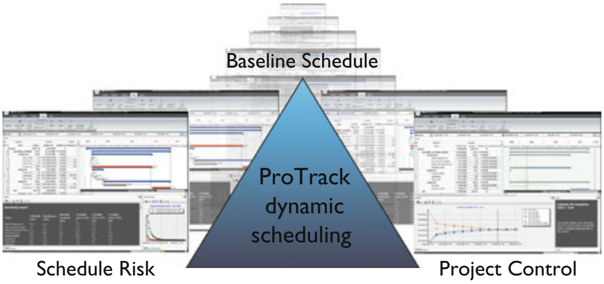

Fig. 15.1 Dynamic scheduling in ProTrack

ProTrack 3.0 has been released in the spring of 2012. In this third release, it has been decided to further develop only the smart version (the most extended ProTrack version) at a much cheaper price. The incorporation of the so-called ProTrack's assistant is one of the main functionalities that has been added to this third release. The main functionalities of ProTrack 3.0 are briefly described in this chapter. For an overview of the four versions of ProTrack 2.0, the reader is referred to Vanhoucke (2010a). As previously mentioned, all functionalities of these four versions have now been integrated in the single ProTrack 3.0 version. For an updated list of the current ProTrack functionalities, check www.or-as.be/protrack. ProTrack's main functionalities are summarized along the following lines:

- **Baseline scheduling:** ProTrack contains the standard baseline scheduling functionalities as discussed throughout this book. It allows the construction of the critical path using forward and backward calculations (see Chap. 2) as well as the incorporation of renewable resources to construct a resource feasible baseline schedule using priority rule based scheduling techniques discussed in Chap. 7.
- **Schedule risk analysis:** ProTrack integrates the option to perform a risk analysis on the baseline schedule using a unique *simulation engine*. More specifically, it allows multiple advanced simulation runs to scan the sensitivity of all project activities, as discussed in the schedule risk analysis Chap. 5.
- **Project control:** Controlling projects using earned value management, including the option to measure the earned schedule and schedule adherence, are basic functionalities of ProTrack 3.0. Most topics discussed in Chaps. 12 and 13 are standard options in ProTrack 3.0.
- **And more:** ProTrack is unique in its kind by incorporating many extra functionalities that make it an ideal learning tool. The automatic generation of project network data using the *project generation engine*, discussed in Sect. 15.5, is an example to facilitate the use of ProTrack for new users. Moreover, the so-called *time forecasting engine* allows the user to go back in time to learn how EVM works for a particular project. More precisely, it allows the generation of fictitious tracking periods from the start till the finish of a project, which automatically generates earned value based tracking information. In doing so, the user can get easily acquainted with the EVM metrics for a project and can also perform

multiple simulation runs to measure how accurate EVM time and cost forecasts are for the project under study. Finally, the project scheduling game discussed in Chap. 3 has also been integrated in ProTrack 3.0.

The outline of this chapter is as follows. In the first three sections, the integration of the dimensions of dynamic scheduling in ProTrack are briefly discussed. Section 15.2 reviews the main project scheduling options available in ProTrack. Section 15.3 reviews how schedule risk analysis can be done while Sect. 15.4 highlights the main earned value management project tracking possibilities of ProTrack. Section 15.5 presents some additional functionalities of ProTrack: the automatic generation of project data, the standard and advanced EVM features and the ability to perform time and cost forecast accuracy calculations. Section 15.6 briefly reviews the features of the project scheduling game of Chap. 3 and Sect. 15.7 draws overall conclusions with links to additional sources of information. The aim of this chapter is not to give a complete overview of the characteristics of ProTrack, but instead to provide a brief overview of how the dynamic scheduling dimensions have been incorporated in the software tool.

15.2 Baseline Scheduling

Throughout the various chapters of this book, it has been continuously mentioned that the construction of a project baseline schedule is often a time-consuming and cumbersome task that nevertheless plays a central role in a schedule risk analysis and in the project control phase. The general starting point of view of this book is 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. Hence, care must be taken to construct a resource feasible and realistic schedule that meets all requirements of the project manager and the members of his/her team.

ProTrack 3.0 contains many of the basic baseline scheduling options discussed in Chaps. 2, 7, 8 and 12 and can therefore be considered as a project scheduling tool similar to many alternative tools available on the commercial market. However, ProTrack 3.0 also makes the connection between baseline scheduling, schedule risk and project control to incorporate all dynamic scheduling dimensions into a single software tool.

15.3 Schedule Risk Analysis

The Schedule Risk Analysis technique discussed in Chap. 5 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's schedule risk analysis makes use of two simulation engines that are hidden behind the simulation screen of the software tool. Both engines serve different needs that can be briefly summarized along the following lines:

- The standard simulation engine allows the user to start a quick and easy simulation without a thorough study on the risk profiles of the various project activities. This standard engine does not require data about estimated probability distributions for the activity durations, but instead makes use of the nine predefined simulation scenarios shown in Fig. 13.5.
- The advanced simulation engine requires a more detailed risk quantification for each project activity using activity duration distributions based on triangular distributions. This advanced engine can be considered as the most advanced schedule risk analysis option in ProTrack, based on the topics discussed in Chap. 5.

ProTrack is able to generate sensitivity measures and reports for the duration and cost of each activity as well as for the resources linked to these activities using the sensitivity measures of Sect. 5.3. Note that the use of these two simulation engines is not restricted to a schedule risk analysis. The two engines can also be integrated with the time forecasting engine to perform a project performance and forecast accuracy study as briefly discussed in Chap. 13. Such an accuracy study, based on real data of fictitious project data will help the user to easily understand the project control dimension of dynamic scheduling in general and earned value management in particular. More information can be found in the book written by Vanhoucke (2010a).

15.4 Project Control

Project control 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.

These and more advanced project control features discussed in Chaps. 12 and 13 are available in ProTrack 3.0.

15.5 ProTrack's Advanced Features

This section briefly reviews some advanced features that are incorporated in ProTrack 3.0. These advanced features are the subject to continuous updates, changes and extensions, and will probably be even more advanced at the time of publication of this book. For an overview of the most recent functionality extensions, the reader can visit ProTrack's website.

15.5.1 Automatic Project Generation

The generation of fictitious project data is an easy and powerful tool to let the user start immediately with ProTrack to gain experience with all its features even before entering real project data. In order to generate a fictitious project that reflects the characteristics of real project data, the user can make use of two project generation options, one measuring the network topology and one related to the use of renewable and nonrenewable (or consumable) resources.

Network Topology

The basic project data required for ProTrack's baseline scheduling can be generated automatically using the following data field:

- 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 of Sect. 8.3.1, which indicates how close the project network lies to a completely parallel (no links) or completely serial (maximum number of links) project.
- Time and cost estimates: The time and cost estimates for each activity will be generated randomly from a user-defined interval. In case the project makes use of renewable and/or nonrenewable resources, the activity cost can be split up into the various resource costs (see Sect. 7.6.1).
- Activity constraints information (cf. Sect. 2.2.4):

– Percentage of tasks with constraints (0–100%), randomly added to the project activities.
– Time window for scheduling: Activity constraints imply a certain date in the project life. The minimal project time window is equal to the critical path (minimum value). This time window can be extended to maximum the double of the critical path (maximum value), and the constraints will be randomly assigned in this time window interval.
– Feasibility of constraints (yes/no): Activity constraint can lead to scheduling conflicts and infeasibilities. Putting the feasible option on avoids these constraints conflicts.

In Chap. 8, it has been shown that the structure of a project network can be measured using various network topology measures. ProTrack allows network topology calculations using the four topology measures of Sect. 8.3.1: the Serial/Parallel indicator SP, the Activity Distribution indicator AD, the Length of Arcs indicator LA and the Topological Float indicator TF.

Automatic Resource Generation

Next to the automatic generation of a project network with a user-defined network structure, all resource related project data can also be automatically generated, allowing the user to set up a fictitious resource-constrained project schedule with a minimum amount of manual interventions. The resource related information needed to automatically generate the resource-constrained schedules can be summarized along the following lines:

1. Generate a user-defined number of renewable and nonrenewable resources. The resource availability of all renewable resources will be set automatically on 100%.
2. Generate values for the resource costs (cost per use and cost per unit) from user-defined ranges.
3. Generate resource demand for the project activities based on some resource scarceness measures of Sect. 8.3.2 using the following parameters:
   - Resource Use: Average number of activities that make use of the resource (expressed as a percentage between 0% and 100% of the activity set of the project).
   - Resource demand values:
     – Average Demand, measured by the Resource Constrainedness (RC). The RC measures the average use of the renewable resource by all project activities relative to its availability, ranging from 0% (no use) to 100% (resource demand is equal to its availability for all activities). Since the renewable resource availability is automatically set to 100% during resource generations, the renewable resource demand of activities is restricted to maximum 100%.

  - Maximum Demand: Maximum number of units requested by the activity for the nonrenewable resources. Since there is no availability of the nonrenewable resource, this number is not restricted to a maximum value.
- User-defined probability values to specify that the nonrenewable resource demand of project activities have a fixed or variable demand, as discussed in Sect. 7.6.

15.5.2 Standard and Advanced EVM Features

ProTrack incorporates all basic and advanced features of project tracking and earned value management discussed in Chaps. 12 and 13. 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 and EAC(t) formulas of Sect. 12.4). 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 activities that have not been started yet is equal to their baseline duration.
- Earned Value Analysis prediction: The schedule predictions using the EVM metrics of Sect. 12.4 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.

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 discussed in Chap. 13. 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. ProTrack provides two alternative views on the project's Gantt chart when showing the p-factor calculations. One shows the tracking Gantt chart, showing real progress of the project and another shows the earned value accrue of the project relative to the baseline schedule (similar to Fig. 13.3).

- Time/Cost forecasting: EVM time and cost forecasting based on the predictive methods of Sect. 12.4.
- Forecast accuracy: ProTrack is an ideal EVM learning tool and contains simulation engines to simulate fictitious project progress to measure the accuracy of time and cost forecasts (see Sect. 15.5.3).
- 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. This Gantt chart can replace the current baseline schedule (i.e. re-baselining) when necessary. Details are outside the scope of this chapter.
- Reporting: A wide range of flexible reports customized with performance measurement metrics, progress updates and resource and cash flow estimates can be easily generated.

15.5.3 Forecasting Accuracy Calculations

ProTrack allows to redo all accuracy studies briefly discussed in Sect. 13.3 using the EVM predictions for the total cost and duration of a project (EAC and EAC(t)) discussed in Chap. 12 and ProTrack's standard simulation engine. In order to evaluate the EAC and EAC(t) forecasting measures and to determine the forecast accuracy of each technique, two straightforward measures are calculated. The measures calculate the average deviations between the total project costs/durations predicted during project execution (the EAC and EAC(t) values at each reporting period) and the final real project cost (RC) and duration (RD) observed after the finish of the project. Obviously, the lower their value, the more accurate the average duration prediction. The two measures are the Mean Percentage Error (MPE) and the Mean Absolute Percentage Error (MAPE). While the MAPE evaluates the forecast accuracy as average absolute deviations between all predictions and the real project time and cost value, the MPE can be calculated in a similar way, but, unlike the MAPE, positive and/or negative values are possible to measure over- and/or underestimations of the final project cost and duration, respectively. In order to calculate these values, the following abbreviations have been defined:

T	Total number of reporting periods over the complete project horizon
RD	Real Duration of the project (known at the project finish)
RC	Real Cost of the project (known at the project finish)
EAC^{t_1}	Cost estimate at reporting period t_1 ($t_1 = 1, 2, \ldots, T$)
$EAC(t)^{t_1}$	Duration estimate at reporting period t_1 ($t_1 = 1, 2, \ldots, T$)

The formulas are displayed in Table 15.1 and a detailed discussion can be found at Vanhoucke (2010a).

Table 15.1 Forecasting accuracy measures in ProTrack

	Time	Cost
MPE	$\frac{1}{T}\sum_{t_1=1}^{T}\frac{EAC(t)^{t_1}-RD}{RD}*100$	$\frac{1}{T}\sum_{t_1=1}^{T}\frac{EAC^{t_1}-RC}{RC}*100$
MAPE	$\frac{1}{T}\sum_{t_1=1}^{T}\frac{\lvert EAC(t)^{t_1}-RD\rvert}{RD}*100$	$\frac{1}{T}\sum_{t_1=1}^{T}\frac{\lvert EAC^{t_1}-RC\rvert}{RC}*100$

15.6 ProTrack as a Teaching Tool

Teaching the impact of the presence of time/cost trade-offs in a reactive scheduling environment using the project scheduling game of Chap. 3 is a basic feature of ProTrack 3.0. Teachers who want to use the game for their project management courses or consultancy services can create their own data and share these data with other ProTrack users, if appropriate.

15.6.1 Simulating Time/Cost Trade-Offs

This section gives a brief overview of some PSG features implemented in ProTrack, without giving any details. More information can be obtained from the PSG tutorial, which can be downloaded from the ProTrack website.

Simulations versus decision making The user must clearly understand the difference between a project simulation and a decision moment. A simulation is a quick and automatic rescheduling test to see the effect of crashing actions taken by the user. From the moment another time/cost combination is taken for an activity, ProTrack automatically reschedules the complete project. Obviously, the software contains an option to go back to the previous project schedule to undo all the actions taken. Intermediate promising schedules can be saved and restored at all times. A decision must be taken when the user is convinced about the quality of the crashing actions taken. It involves the automatic simulation of fictitious project progress under uncertainty and leads to an increase in the actual time pointer. Obviously, there is no option to go back in time and undo the decision of the user.

Access to the game ProTrack owners have full access to the data of the PSG. This includes access to the uncertainty level, project network, time/cost combinations, time limit and number of decision periods. PSG users (e.g. students) only have limited access since they are not allowed to change the underlying project data.

15.6.2 Submitting Project Data

The project scheduling game contains a default project network (see Fig. 3.5), which allows the users to immediately start up the simulation game without additional setup time. However, the most interesting teaching session will be given to an audience that is familiar with the project and its underlying project network features. To that purpose, the PSG functionality of ProTrack can be extended with other projects that satisfy the needs of the user and that reflects the characteristics of the project environment of the software user.

ProTrack PSG users are stimulated to submit their own data via the www.protrack.be/psg support page or via the personal support page of ProTrack owners. The reasons why ProTrack users should submit their own developed project data for the PSG simulation can be twofold:

- Share the example projects with other PSG users: When submitting a project, the users can choose to share their data with other ProTrack users. In doing so, a database of interesting project networks applicable for PSG simulation runs can be created with projects from different sectors. Moreover, it has been said in Sect. 3.4.5 that the game might act as a research tool, and hence, submitting data will certainly contribute to that goal.
- Complete time/cost profile: Obviously, it is interesting to have an idea about the best possible time/cost profile for the projects developed by users. A best known time/cost profile, similar to Fig. 3.9, allows the user to validate the solution obtained by a PSG run. When data is submitted to the website in a correct ProTrack-PSG format, a solution will be posted on the support page of the software user. The data submitted will be entered in a software tool in order to find the best possible time/cost profile for the project. The optimal time/cost profile will be found by the algorithm of Demeulemeester et al. (1998) or, in case the optimal solution can not be found due to the size of the project, a heuristic solution will be found by the algorithm of Vanhoucke and Debels (2007).

15.7 Conclusions

Project tracking and control constitute the heart of any scheduling tool and play a central role in ProTrack. They all combine Gantt chart schedule forecasts and Earned Value Management performance measurements to control the progress of a project and to make accurate predictions about the future. ProTrack makes use of basic and more advanced state-of-the-art EVM approaches to measure the time and cost performance of a project in a reliable way.

Ideally, a project tracking approach should use all relevant information that project managers have obtained during the construction of the project network and should rely on data from the baseline scheduling step as well as information from the schedule risk analysis phase. This dynamic scheduling approach is the main topic throughout all previous chapters of this book, and is set up as a central theme in ProTrack. More specific information about ProTrack's specific characteristics, the continuous updates and many detailed features can be found in the free ProTrack tutorials; which can be downloaded from www.protrack.be.