Chapter 13
Advanced Topics

Abstract This chapter gives an overview of the main Earned Value Management (EVM) research results obtained by a large Monte-Carlo simulation study summarized in the book by Vanhoucke (2010a). The focus is on the prediction of the final duration of a project in progress using the forecasting methods of Sect. 12.4.1. The chapter measures the accuracy of these prediction methods and the main drivers of this accuracy along the various stages in the project life cycle. The chapter also presents a rather new EVM extension, the so-called p-factor approach, to measure schedule adherence based on the traditional earned value metrics. Finally, the chapter presents the main results of integrating the three components of dynamic scheduling (baseline scheduling, risk analysis and project control) and investigates whether the integrated approach might lead to a higher efficiency of the project control phase during its progress.

13.1 Introduction

The literature on the three components of dynamic scheduling is rich and widespread, and has led to numerous algorithms, techniques and software tools to better schedule and control a project. Little is known, however, on the contribution of these tools and techniques to the overall success of the project. While many research efforts have investigated the dynamic scheduling components in isolation, the central research question should be "Does dynamic scheduling as an integration between project scheduling, risk analysis and project control lead to better projects?". Although it is conjectured that a clever use of the three components of dynamic scheduling certainly contributes to a better project performance, this very ambitious question will not be completely answered in this book. However, research might be able to give partial answers to this question, which, in the long run, enables project managers to understand the driving factors of project success. Research has, by nature, a very forward looking attitude, and project success comes from trying and failing and subsequently, from understanding the failure. In order to have a long term success in projects, companies should foster the attitude of

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experimentation. Research serves that purpose very well, which is exactly the reason why this more advanced chapter has been incorporated in this book. It is also in the nature of research that many results can be critically interpreted or sometimes rejected by other conflicting results. The need for research to objectivize the various opinions on Earned Value Management and the knowledge that research goes hand in hand with trying and failure have to be seen as expectations in the search for something new, and not something to be seen as waste.[1] This chapter has no intention to offer a final answer to the general project success question nor to claim that it holds the general truth on dynamic scheduling. It, however, hopes that this research is a step into the right direction, which hopefully may inspire many other researchers and practitioners to continue to test and experiment with ideas of dynamic project scheduling, and to share their idea with the project management community. The research summarized in this chapter is inspired by many people, among whom Stephan Vandevoorde (Belgium), Walt Lipke (US) and Kym Henderson (Australia) played a central role. The help and support by many members from the Belgian chapter of the Project Management Institute (PMI) and International Project Management Association (IPMA) is also greatly acknowledged.

The outline of this chapter can be summarized as follows. Section 13.2 present a more advanced concept, known as schedule adherence, which completely relies on the EVM metrics discussed in the previous chapter. Section 13.3 presents the main results of a simulation experiment to investigate the accuracy of various EVM methods to predict the final duration of a project. Section 13.4 integrates these results on the accuracy study with the schedule risk analysis results of Chap. 5 into an integrated project control approach. Moreover, in this section, computational results on the efficiency of alternative project control methods are presented. Section 13.5 gives an overall conclusion and directions for future research.

13.2 Schedule Adherence

Since the introduction of the Earned Schedule (ES) concept (Lipke 2003) as a time related extension of the well-known Earned Value metrics (see Sect. 12.2.4), studies on the time dimension of EVM have been published throughout the popular and academic literature.

Despite the ever growing positive attention to EVM and the commonly accepted agreement on the importance of EVM in a project control environment, both EVM in general and ES more specifically have not been free of criticism. The basic criticism on an EVM system is its assumption of a project setting where activities and precedence relations are known in advance and where estimates (activity durations, resource requirements, unexpected events, etc.) can be given

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[1] I learned this very positive attitude from Walt Lipke, who always supported any research idea, even if it sometimes led to counterintuitive or wrong results.

within a certain range. However, Loch et al. (2006) mentioned that projects often do not fulfill these assumptions but, on the contrary, are commonly plagued by fundamentally unforeseeable events and/or unknown interactions among various actions and project parts. Consequently, due to the cycles of rework, the accuracy of the EVM metrics can be biased, leading to incorrect management decisions (Cooper 2003).

While the criticism on EVM in general is related to uncertainty characterized by most project environments, the criticism on the ES concept is more related to the questionability of the novelty of the concept and the correctness of the underlying ES formula (Book 2006b; Abba 2008). Despite this criticism, research studies have shown that it offers a valuable alternative to the traditional EVM time forecasting methods (Vanhoucke and Vandevoorde 2007b) and often produces more reliable results.

The p-factor concept is yet another extension on the EVM method and will undoubtedly be part of criticism. Since this new concept has only been introduced as an idea in 2004 and has not yet passed the test of logic, it deserves more attention to test its merits in a dynamic project control environments. Therefore, it needs to be investigated into more detail in order to reveal its strengths and weaknesses. The purpose of this chapter is only to give a start to such a deeper analysis, without claiming to provide a full overview with state-of-the-art methodological details.

13.2.1 The p-Factor Concept

The rationale behind the p-factor approach lies in the observation that performing work not according to the baseline schedule often indicates activity impediments or is likely a cause of rework. Consequently, the premise is that, whenever impediments occur (activities that are performed relatively less efficiently compared to the project progress), resources are shifted from these constrained activities to other activities where they could gain earned value. However, this results in a project execution that deviates from the original baseline schedule and might, consequently, involve a certain degree of risk. Indeed, the latter activities are performed without the necessary inputs, and might result into a certain portion of rework. Based on these observations, the p-factor has been introduced by Lipke (2004) as a measure to provide the connection of project output to EVM. It measures the portion of earned value accrued in congruence with the baseline schedule, i.e. the tasks that ought to be either completed or in progress, as follows:

$$\mathrm{p} = \frac{\sum_{i \in N} min(\mathrm{PV}_{i,\mathrm{ES}}, \mathrm{EV}_{i,\mathrm{AT}})}{\sum_{i \in N} \mathrm{PV}_{i,\mathrm{ES}}}$$

with

p Schedule adherence
= 1: perfect schedule adherence
< 1: lack of perfect schedule adherence

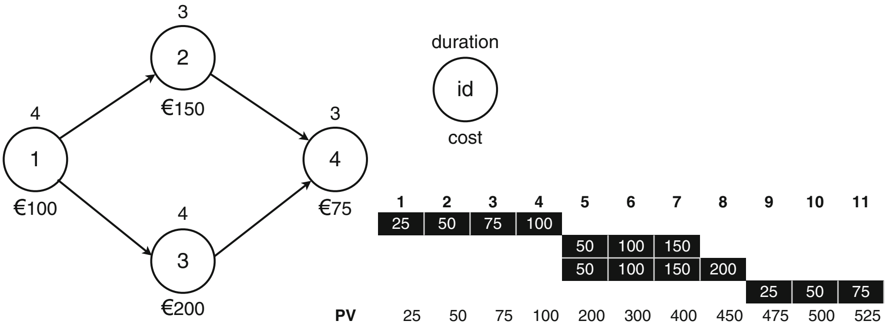

Fig. 13.1 A fictitious four-activity project network

N	Set of activities in the project
$\text{PV}_{i,\text{ES}}$	Planned value of activity i at time instance ES
$\text{EV}_{i,\text{AT}}$	Earned value of activity i at the actual time AT

Despite the simplicity of the p-factor formula, it is often subject to confusion. Figure 13.1 shows a fictitious four-activity project with each activity having a predefined duration (above the node) and cost (below the node). An earliest start baseline schedule is shown to the right of this figure, with a planned duration PD = 11 weeks and a budget at completion BAC = €525. The values in the bars of the Gantt chart are cost accrues over time. The figure shows that the planned value accrue is linear, from €0 at the start of the activity to the final activity cost upon completion. In order to illustrate the calculations of the p-factor, a baseline schedule and three possible project executions will be simulated and discussed.

The simulated project progress under the four scenarios is illustrated in Fig. 13.2. Each fictitious project execution represents a different situation, which can be summarized as follows:

1. Activity overlapping: The p-factor concept does not take precedence relations into account, but instead takes a general project view on the schedule adherence. Nevertheless, it should be able to detect the presence of overlaps, which is probably the main reason for lack of information and risk of rework. Figure 13.2a gives an illustration of an overlap between two activities in series, and shows that the p-factor is able to detect this situation.
2. PV/EV accrue deviations: Activities that are completed within their estimated time and budget are not necessarily performed in congruence with their predefined planned value. Since the p-factor is a concept to measure the degree of adherence to the baseline schedule, expressed as a relation between the project progress (Earned Value) and the baseline schedule (Planned Value), it should be able to give an indication of the deviation between PV and EV. In Fig. 13.2b, the EV accrued during the real life project progress is not in line with the PV

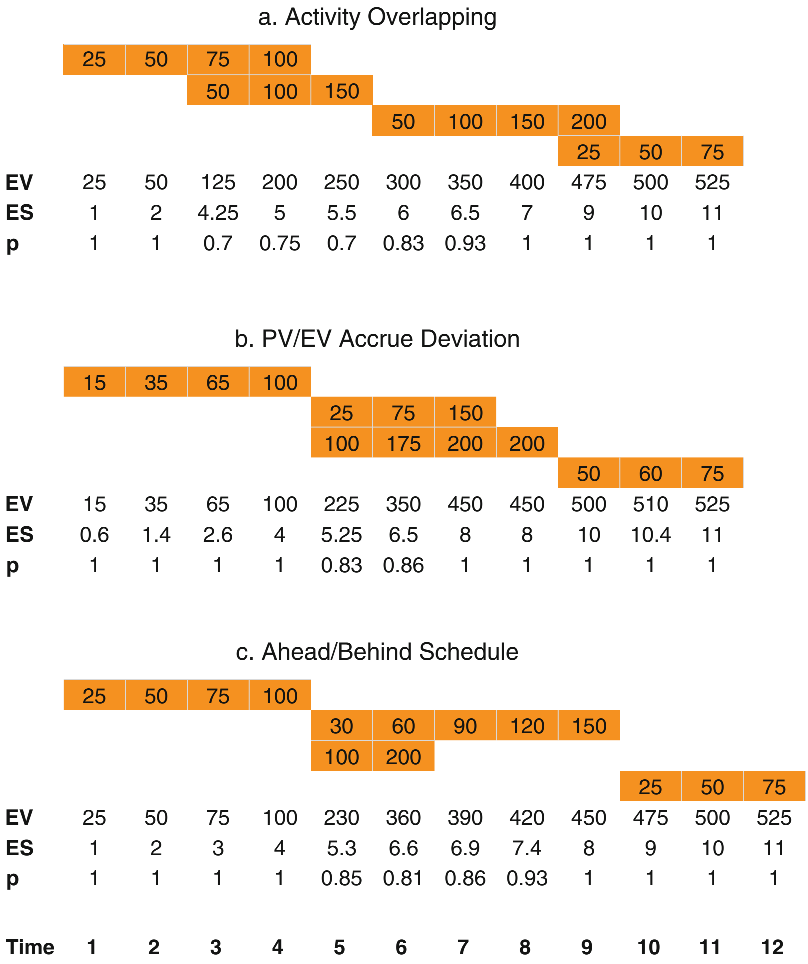

Fig. 13.2 A fictitious four-activity project under three progress scenarios

accrue of the baseline schedule, although the project finishes exactly on time. The p-factor measures this lack of schedule adherence.

3. Ahead of schedule and/or delayed project execution: Obviously, deviations from the original baseline schedule during project progress lead to a final project status ending ahead or late. This lack of schedule adherence should be measured and reported by the p-factor concept in order to serve as a dynamic tool to forecast the final project status. Figure 13.2c shows a situation of a delayed project with activities finishing ahead of and behind schedule, resulting in p-factor values lower than 1.

Table 13.1 Illustrative calculations for the p-factor at review period 6 of Fig. 13.2b

Activity	$PV_{i,ES}$	$EV_{i,AT}$	$\min(PV_{i,ES}, EV_{i,AT})$
1	100	100	100
2	125	75	75
3	125	175	125
4	0	0	0
	350		300

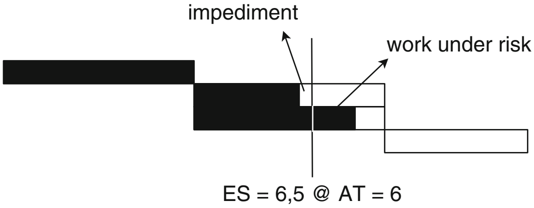

Fig. 13.3 Activity impediments and work under risk to measure the p-factor

Table 13.1 illustrates the calculations of the p-factor for the Gantt chart of Fig. 13.2b at review period $AT = 6$. The earned schedule at $AT = 6$ is $ES = 6.5$ and the p-factor is equal to $300/350 = 0.86$.

13.2.2 *Effective Earned Value*

The p-factor assumes that lack of schedule adherence is caused by a combination of the presence of impediments or constraints and work performed under risk. Figure 13.3 shows an intermediate project progress state at the actual time $AT = 6$ for the project progress of Fig. 13.2b relative to the baseline schedule. This means that the baseline schedule is displayed and the black bars are used to express the activity percentage completed as $PC = \frac{EV}{BAC}$ at the current time instance 6. Consequently, the EV accrued at the current time $AT = 6$ is given in black and the $ES = 6{,}5$. The figure visualizes the p-factor as follows:

- The portion of the work to the left of the ES line is assumed to be performed without risk and indicates the presence of an impediment or project constraint.
- The portion of work to the right of the ES line indicates work that is ahead of the normal project performance and is assumed to have a certain degree of risk.
- The p-factor is equal to the EV (black bars) to the left of ES line divided by the total EV.

Figure 13.3 shows that activity 2 has a lower EV (€75) at time 6 than normally should have been earned at time instance 6.5 (€125), while the opposite is true for activity 3 (EV at time 6 (€175) is higher than PV at time 6.5 (€125)).

It is assumed that this degree of risk is the result of inefficient use of resources that were shifted from the constrained activities to less constrained activities where the resources could gain earned value. However, these shifted resources work without the necessary inputs possibly resulting in a certain portion of rework (i.e. risk). The p-factor is a measure to express the portion of the EV without risk (referred to as EV(p)), while the remaining portion is denoted as EV(r).

A project manager should realize that the remaining EV(r) portion might be subject to risk and possibly results in rework. The *effective earned value* EV(e) is defined as the risk-adapted portion of earned value that is performed within the expected baseline schedule performance, taking into account that only R% of the EV(r) will be accounted as risk-free. Mathematically, these p-factor assumptions can be summarized as follows:

$$\mathrm{EV} = \mathrm{p} * \mathrm{EV} + (1 - \mathrm{p}) * \mathrm{EV} = \mathrm{EV(p)} + \mathrm{EV(r)} \rightarrow \mathrm{EV(e)} = \mathrm{EV(p)} + \mathrm{R\%} * \mathrm{EV(r)}$$

with

EV	Earned value
EV(p)	Risk-free earned value
EV(r)	Remaining earned value portion performed under risk
EV(e)	Effective earned value
R%	Estimated portion of EV(r) that is usable and requires no rework

More details on the schedule adherence concept are outside the scope of this book and can be found in Lipke (2004) and Vanhoucke (2010a).

13.3 If Time Is Money, Accuracy Pays!

In this section, the scope and the main results of an experimental study in search for drivers of forecast accuracy using Earned Value Management techniques are briefly summarized. The concepts used in this study have been explained in Chaps. 5 and 12 and aim at an integration of Earned Value Management (EVM) and Schedule Risk Analysis (SRA) in order to better control projects.

13.3.1 Research Scope

The scope of the research study is a detailed investigation of project time performance measurement methods and risk analysis techniques in order to validate current and newly developed methods to improve the corrective actions decision making process during project control. More precisely, the target of the research proposal is to measure the project performance sensitivity and the forecast accuracy of the existing and newly developed metrics based on the principles of EVM and SRA. The research question boils down to the determination of when and in which cases SRA and EVM could lead to improved project tracking and corrective actions decision making.

The specific targets and research hypotheses formulated in the research project can be summarized as follows:

- What are the static (before project execution) and dynamic (during project execution) drivers of forecast accuracy? Knowledge about project performance drivers and accurate forecast accuracy measures should allow the project manager to critically analyze EVM performance measures and to accurately predict the final cost and duration of a project. Static and dynamic drivers that have been investigated in detail are:
  - Static drivers:
    - Project network topology: Characteristics of the project can be easily calculated during the construction of the baseline schedule, and affect the accuracy of the performance measurement during project tracking.
    - Activity criticality: The degree of activity criticality affects the project tracking process and the performance accuracy.
  - Dynamic drivers:
    - Schedule adherence: The project schedule and the adherence to that schedule (in terms of precedence logic, EVM measurement system, etc.) should have an effect on the accuracy of project performance measurement.
    - Time span of control: The time span and the number of review periods during project performance measurement clearly affect the accuracy.
- How does the project time sensitivity affect the accuracy of performance measurement? Information obtained during the scheduling step (baseline plan) as well as sensitivity information and risk analysis obtained through SRA should allow the project manager to improve the project tracking process and the decision making process for corrective actions.
- How does the knowledge on forecast accuracy (two previous research questions) lead to improved corrective actions decision making during project tracking? Since EVM is a methodology to provide an often quick sanity check of the project health on the cost control account level or even higher Work Breakdown Structure (WBS) levels, it cannot be considered as an alternative of the often time-consuming activity-based Critical Path Method (CPM) scheduling approach. The research aims at detecting when and how the EVM tracking approach offers a full alternative to the detailed CPM project tracking, and in which cases a need to drill down to lower WBS levels is necessary to take corrective actions.

In the remaining sections, the methodological approach and the main results are briefly summarized.

13.3.2 Research Methodology

The methodology used can be summarized as a four step procedure as outlined in Fig. 13.4. The approach makes use of the baseline scheduling principles discussed

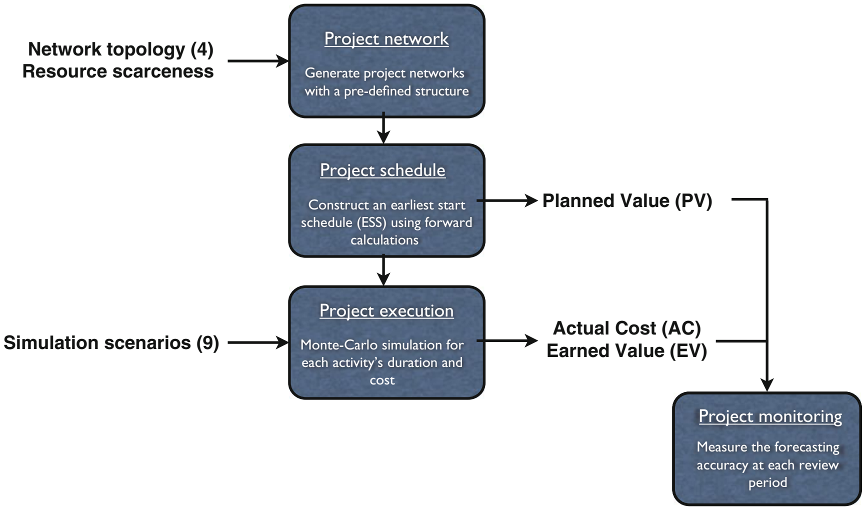

Fig. 13.4 The four step research methodology used for the EVM accuracy study

in Parts I and II of this book, and calculates the performance of the project using techniques that will be presented in Chap. 12.

1. Generate project data: In order to guarantee that the set of project data spans the full range of complexity, network topology measures and resource scarceness measures are used under different settings. Section 8.3 briefly reviewed these network and resource measures. In the study, more than 4,000 fictitious project networks have been generated with the software tool presented in Chap. 15.
2. Construct a project schedule: The construction of a feasible project schedule taking into account precedence relations and renewable resource constraints is one of the main topics of this book and belongs to the project scheduling part of the dynamic scheduling approach. Each project is scheduled with a minimal time scheduling objective, resulting in a planned value curve (PV) necessary to use EVM and a planned project duration PD.
3. Simulate project progress: Project progress results in uncertainty and deviations from the original baseline schedule. Fictitious progress requires a predefined set of scenarios to control the level of project uncertainty and schedule deviations. Each project progress is simulated under nine different scenarios while carefully controlling the nature of the uncertainty. Periodic reviews of the project performance resulted in values for the actual cost (AC) and earned value (EV). Project progress is simulated using Monte-Carlo simulation, and hence, this step can be considered as a Schedule Risk Analysis (Chap. 5).
4. Measure forecast accuracy: During the periodic reviews, all EVM data are available (PV, AC and EV) to measure the time and cost performance of the project, and to forecast the total time (EAC(t)) and cost (EAC) of the project. These predictions are compared with the final real project duration (RD), and deviations are observed as indications of lower forecast accuracy. The current

study calculates the accuracy of the EAC(t) predictions (and not the EAC formulas).

The nine simulation scenarios to simulate fictitious project progress can be explained using Fig. 13.5. Each of the nine boxes makes use of the following abbreviations:

Critical and noncritical activities:

Activity duration uncertainty (deviation from schedule)
– : Activity ahead of schedule
0 : Activity on time
\+ : Activity delay

EVM Performance measurement (during progress):

$\overline{SPI(t)}$: 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):

PD and RD : Planned and Real Duration of the project
RD = PD : Project on time
RD >PD : Late project
RD <PD : Early project

Note that the $\overline{SPI(t)}$ is not the schedule performance index at a current moment in time, as used in the previous chapter, but instead an average of all SPI(t) values measured at regular project tracking intervals. Consequently, this value gives the average performance measured by EVM metrics over all reporting periods in the project life cycle.

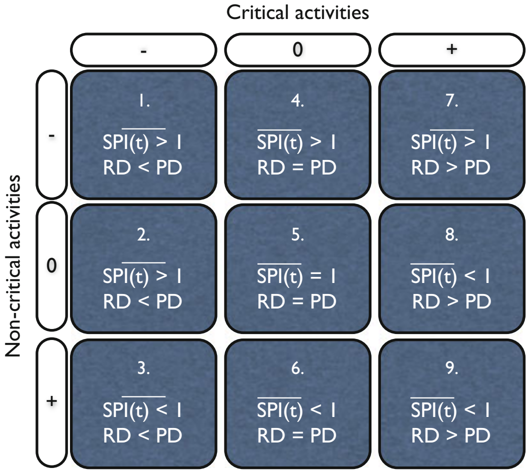

Fig. 13.5 Nine simulation scenarios (step 3 of Fig. 13.4)

The nine simulation scenarios can be classified into three categories, each having a different meaning and purpose, as follows:

True scenarios: Scenarios 1 and 2 report an average project 'ahead of schedule' progress ($\overline{\mathrm{SPI(t)}} > 1$) and the project finishes earlier than planned ($\mathrm{RD} < \mathrm{PD}$). Scenarios 8 and 9 report an average 'project delay' progress ($\overline{\mathrm{SPI(t)}} < 1$) and the project finishes later than planned ($\mathrm{RD} > \mathrm{PD}$). Scenario 5 reports an 'on-time' progress ($\overline{\mathrm{SPI(t)}} = 1$) and the project finishes exactly on time ($\mathrm{RD} = \mathrm{PD}$). Consequently, these five scenarios report on average a true situation (i.e. what you measure is what you get).

Misleading scenarios: Scenario 4 reports an average project 'ahead of schedule' progress ($\overline{\mathrm{SPI(t)}} > 1$) but the project finishes exactly on time ($\mathrm{RD} = \mathrm{PD}$). Likewise, scenario 6 reports an average 'project delay' progress ($\overline{\mathrm{SPI(t)}} < 1$) but the project finishes exactly on time ($\mathrm{RD} = \mathrm{PD}$). Consequently, these two scenarios report on average a schedule deviation that is not true, and hence, they are called misleading simulation scenarios.

False scenarios: Scenario 3 reports an average 'project delay' progress ($\overline{\mathrm{SPI(t)}} < 1$) but the opposite is true: the project finishes earlier than planned ($\mathrm{RD} < \mathrm{PD}$). Scenario 7 reports an average project 'ahead of schedule' progress ($\overline{\mathrm{SPI(t)}} > 1$) but the opposite is true: the project finishes later than planned ($\mathrm{RD} > \mathrm{PD}$). Consequently, these two scenarios report a false performance signal, and hence, they are called false simulation scenarios.

13.3.3 Drivers of Forecast Accuracy

In this section, the simulation results are analyzed in search of drivers that influence the accuracy of earned value based predictive methods to forecast a project's final duration. A distinction is made between *static drivers*, which can be calculated before the start of the project (i.e. during the definition and scheduling phases) and *dynamic drivers*, which can be calculated during the project's execution phase. These drivers will be discussed in the next subsections. Details on the research methodology and more extended results can be found elsewhere in literature by Vanhoucke and Vandevoorde (2007a,b, 2008, 2009) and Vanhoucke (2008a,b, 2009, 2010b).

Static Drivers of Forecast Accuracy

The static drivers during the preparation phases of the project (i.e. the definition and scheduling phases) have been displayed in Fig. 13.6, and will be summarized along the following lines of the section.

Definition phase – Influence of network topology: The topological structure of a project network, defined by the number and distribution of the activities and their precedence relations, can be easily measured through the use of often simple

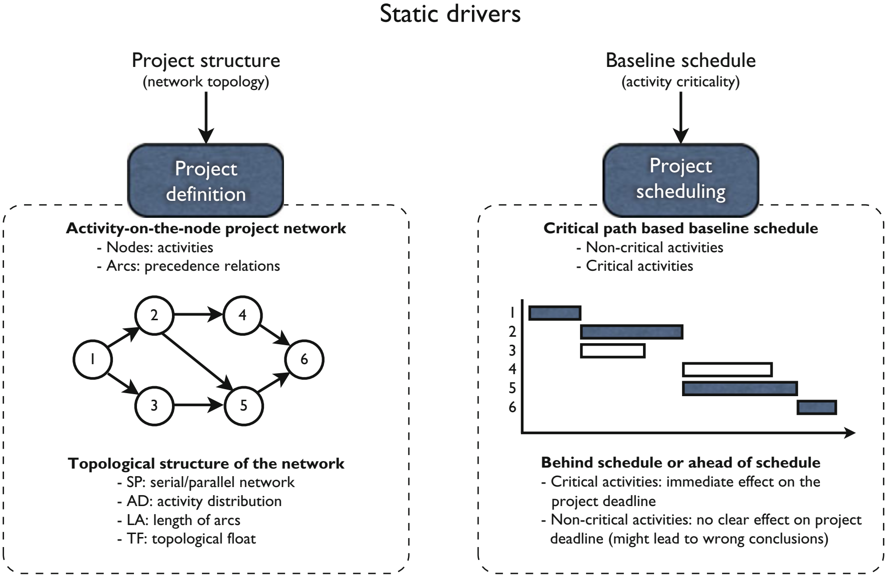

Fig. 13.6 Static drivers of EVM accuracy: project definition and scheduling phase

mathematical calculations of indicators that distinguish between various structures of project networks (see Sect. 8.3.1). These indicators serve as measures of diversity able to detect project networks that differ substantially from each other from a topological structure point of view. The test results have revealed that there is a strong influence of the serial/parallel topological indicator SP on the accuracy of EVM predictive methods. The indicator measures the closeness of a network to a completely serial or completely parallel network and the simulation results clearly show that the more the project network looks like a serial network, the higher the accuracy of the EVM methods to predict the final project duration.

Scheduling phase – Influence of activity criticality: Project scheduling aims at the construction of a baseline schedule where each activity is sequenced subject to the precedence constraints (Part I of this book) and resource constraints (Part II). Traditional scheduling methods result in the presence of a critical path (or alternatively, a critical chain when resources are present). The activity criticality heavily determines the accuracy of earned value based metrics, since changes (delays or accelerations) in critical activities have an immediate effect on the project duration, while changes in noncritical activities might have no effect at all on the final duration of the project. It is exactly for this very reason that Jacob and Kane (2004) argue that the well-known EVM performance measures (SPI, SPI(t), ...) are true indicators for project performance as long as they are used on the activity level and not on the control account level or higher Work Breakdown Structure (WBS) levels. As an example, a delay in a noncritical activity might give a warning signal that the project is in danger, while there is no problem at all when the activity only consumes part of its slack. When the performance measures are calculated on the project level, this will lead to a false warning signal and hence, wrong corrective actions could be taken. However, in the simulation study, these performance measures are calculated on the project level, and not on the level of each individual activity, for very pragmatic reasons. It is recognized that effects (delays) of nonperforming activities can be neutralized by well performing activities (ahead of schedule) at higher WBS levels, which might result in masking potential problems, but it is common belief that this is the only approach that can be easily taken by practitioners (see e.g. the note given in the paper by Lipke et al. (2009) and the conclusions and recommendations at the end of the previous chapter). The earned value metrics are set up as early warning signals to detect in an easy and efficient way (i.e. at the cost account level, or even higher), rather than a simple replacement of the critical path based scheduling tools. This early warning signal, if analyzed properly, defines the need to eventually drill down into lower WBS levels. In conjunction with the project schedule, it allows to take corrective actions for those activities that are in trouble (especially those tasks that are on the critical path). The simulation results have shown that the average activity criticality has a clear influence on the accuracy of the predictive methods as follows: the higher the activity criticality, the better the accuracy of the forecasts. Obviously, a lower activity criticality means a lower probability of being on the critical path, and hence, the more likely a delay (within the activity slack) reported by the SPI and SPI(t) indicators has no effect on the final project deadline.

Dynamic Drivers of Forecast Accuracy

Figure 13.7 gives an overview of the dynamic drivers of EVM forecast accuracy during the life of the project. The adherence of a project to the original baseline schedule (during the execution phase) as well as the choice of the length of the control periods of a project in progress provide dynamic information about the accuracy of the project schedule performance. Details of these two sources of dynamic information parameters are described along the following lines.

Execution phase – Influence of degree of schedule adherence: During the execution of the project, the original activity timetable can be disrupted due to numerous reasons leading to a project execution that is not in congruence with the original baseline schedule. This lack of schedule adherence can be dynamically measured through the use of the p-factor as described in Sect. 13.2.1. While the ES metric measures the current duration performance compared to the baseline schedule and indicates whether the project is ahead or behind schedule, the p-factor measures the performance of the project relative to this ES metric, and hence, measures the degree of schedule adherence given its current (good or bad) performance up-to-date. The simulation experiment has revealed a negative relation between the average p-factor and the forecast accuracy, i.e. lower p-factor values denoting a certain lack of

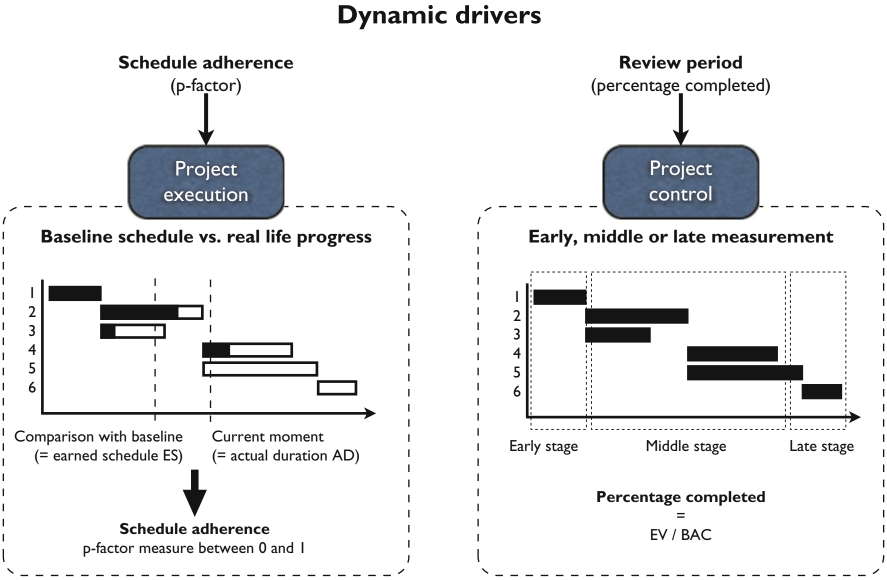

Fig. 13.7 Dynamic drivers of EVM accuracy: project execution and control phase

schedule adherence often result in less accurate forecasts. Hence, the p-factor, which can be dynamically measured during a review of the project (i.e. project tracking) based on the traditional EVM metrics, can be considered as a dynamic warning signal of the duration forecast accuracy.

Control phase – Influence of completion stage: During the control phase, the decision maker (i.e. the project manager) has to determine the length of the review periods as well as the interval in which EVM based predictive metrics might produce reliable results. A crucial assumption of EVM based forecasting is that the prediction of the future is based on information of the performance from the past, and hence, unreliable data from the past might give false predictions to the future. It is therefore of crucial importance to determine the time window in which the EVM metrics produce more or less reliable results. Undoubtedly, the accuracy of forecasts depends on the completion stage of the project. Obviously, the EVM metrics measured at the very beginning of the project are often very unreliable due to the lack of sufficient data to assume that future performance will follow the current performance up-to-date. For these reasons, the accuracy of index-based time forecasts is measured as a function of the completion stage of the project, given by the percentage completed EV/BAC. The average accuracy of these predictions made in the early, middle and late stages of the project execution phase is determined, both for projects ahead of schedule or for projects with a delay. The early stage is defined as the first 30% of the project completion, the middle stage is defined as the interval between 30% and 70% completion and the late stage equals the last 30%

completion of the project. The results from the experiments have shown that the Earned Schedule method outperforms, on average, the other forecasting methods (Planned Value and Earned Duration methods, see Table 12.2) in all stages of the project execution phase. The results also illustrate the unreliable behavior of the SPI indicator (used in the planned value and earned duration methods) at the late stage of the project. Indeed, the late stage forecast accuracy is much better for the ES method compared to the PV and ED methods. The results for the planned value method show that the use of the SPI indicator, which goes to a final value of 100%, regardless of the project performance, leads to very low quality predictions at the late stage of the project. The SPI(t) indicator of the earned schedule method has been developed to overcome this unreliable behavior, leading to an improved forecast accuracy at the end of the project. Obviously, measuring project performance and predicting future performance based on the resulting data leads to the lowest accuracy at the early stages of the project execution phase.

13.4 Project Tracking Efficiency

The main theme of this book, referred to as dynamic scheduling is used to refer to dynamic interplay between its three components: baseline scheduling, schedule risk and project control. The construction of a baseline schedule plays a central role in a dynamic scheduling environment, both for measuring schedule risk and in a project control environment. Schedule Risk Analysis (SRA – Chap. 5) is a technique to measure the sensitivity of project activities and to predict the expected influence of variability in activity durations/costs on the project objective. A schedule risk analysis study is done based on Monte-Carlo simulations that repetitively simulate project progress and compare each project run with the baseline schedule. Earned Value Management (EVM – Chap. 12) is a project tracking and control technique which compares the project performance relative to the baseline schedule. Figure 13.8 shows the three building blocks of dynamic scheduling and

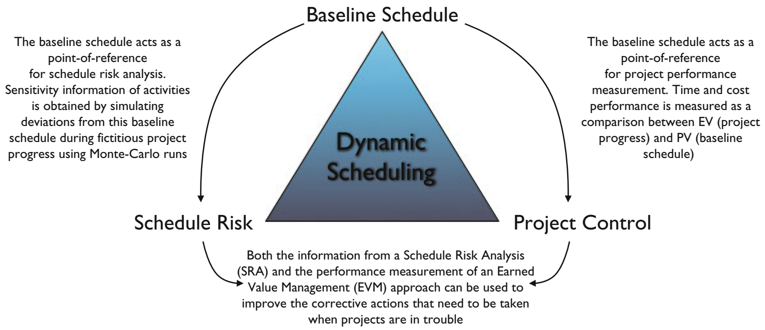

Fig. 13.8 Does dynamic scheduling lead to a higher efficiency in project tracking?

shows the relevance of the baseline schedule as a point of reference for both schedule risk and project control.

The focus of the current section is on the importance and crucial role of the baseline scheduling component for the two other components, and the integration of the schedule risk and project control component in order to support better corrective action decision making when the project is in trouble. While previous results have shown that EVM metrics provide good and accurate forecasts for some projects (see Sect. 13.3.3), it is still an unanswered question whether a higher degree of accuracy leads to a better decision making process during the project execution phase. More precisely, the topic of this section is to discuss the missing link in the dynamic scheduling principle: can schedule risk analysis and earned value management be integrated into a single project tracking approach to better support the decision making process of corrective actions? The next two sections briefly discuss this topic, without going into many technical details.

13.4.1 Top-Down Project Tracking Using EVM

It has been mentioned throughout this chapter that project tracking using earned value management should not be considered as an alternative to the well-known critical path based scheduling and tracking tools. Instead, the EVM methodology offers the project manager a tool to calculate a quick and easy sanity check on the control account level or even higher levels of the work breakdown structure (WBS). In this respect, an earned value management system is set up as an early warning signal system to detect problems and/or opportunities in an easy and efficient way, which is obviously less accurate than the detailed critical path based scheduling analysis of each individual activity. However, this early warning signal, if analyzed properly, defines the need to eventually drill down into lower WBS levels. In conjunction with the project schedule, it allows taking corrective actions on those activities that are in trouble (especially those tasks which are on the critical path). In this section, this *top-down tracking approach* is called a *project based tracking method*. Figure 13.9 displays a fictitious work breakdown structure (WBS) to illustrate the project based project tracking approach of earned value management.

13.4.2 Bottom-Up Project Tracking Using SRA

Figure 13.10 illustrates the *bottom-up tracking approach* of schedule risk analysis, which is the topic of Chap. 5. The detection of activity sensitivity information is crucial to steer a project manager's attention towards a subset of the project activities that have a high expected effect on the overall project performance. These highly

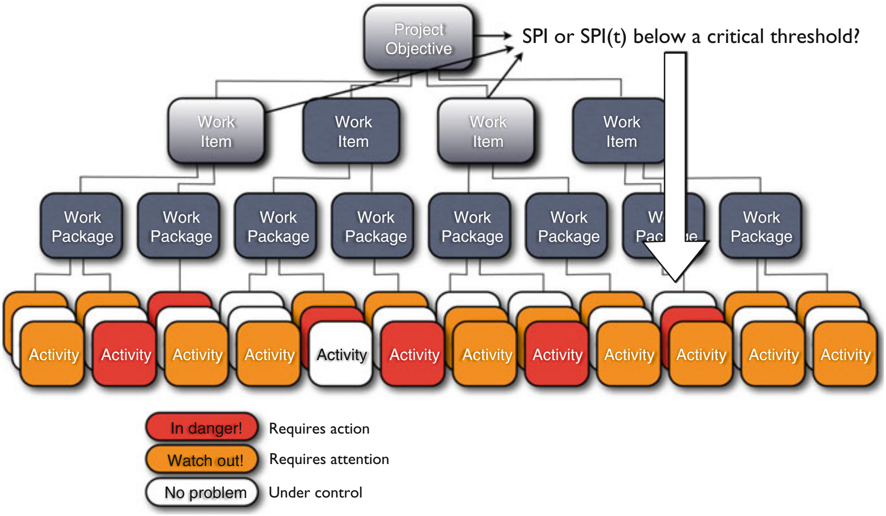

Fig. 13.9 The top-down project based tracking approach of earned value management

sensitive activities are subject to intensive control, while others require less or no attention during project execution. This approach is referred to as an *activity based tracking approach* to denote the bottom-up control and tracking approach to take corrective actions on those activities with a highly expected effect on the overall project objective. This bottom-up project tracking approach has been previously discussed using Fig. 5.7.

13.4.3 Project Tracking Efficiency

Vanhoucke (2010a) has experimentally validated the efficiency of the two alternative project tracking methods of Figs. 13.9 and 13.10. In this study, the efficiency of corrective actions taken on a project in trouble is measured for various projects, ranging from parallel to serial projects. Those corrective actions are triggered by information obtained by a schedule risk analysis (bottom-up) or an EVM warning signal (top-down). Figure 13.11 shows an illustrative graph of this tracking efficiency for both tracking approaches, as follows:

- The x-axis shows the network topology of all projects of the study. The network topologies of the projects are measured by the Serial/Parallel SP indicator of Sect. 8.3.1 and range from completely parallel to completely serial networks.

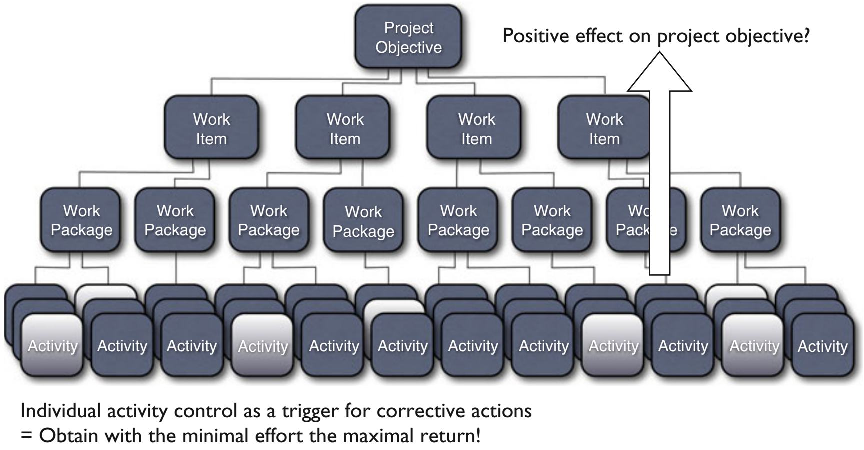

Fig. 13.10 The bottom-up activity based tracking approach of schedule risk analysis

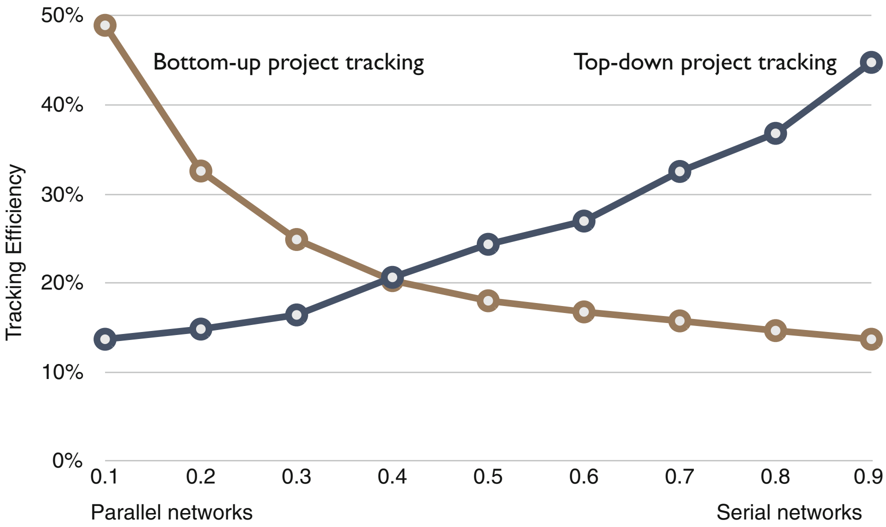

Fig. 13.11 The tracking efficiency of a bottom-up and top-down tracking approach

- The y-axis displays the efficiency of the project control phase. The lower the effort is for a project manager in controlling a project in progress and the higher the positive return is of corrective actions taken by the project manager in case the project is in danger, the higher the tracking efficiency is.

The graph clearly demonstrates that a top-down project based tracking approach using the EVM performance measures leads to a very efficient project tracking approach when the project network contains more serial activities. It should be noted that this top-down approach makes use of the SPI(t) indicator to predict the final duration, and not the SPI indicator, which is known to provide unreliable predictive performance results (see Chap. 12). The bottom-up activity based tracking approach using sensitivity information of activities obtained through a standard schedule risk analysis is particularly useful when projects contain a lot of parallel activities. This bottom-up approach requires often subjective distribution information of individual activities, which implies a certain activity risk estimate, but simplifies the tracking effort to those activities with a high expected effect on the overall project objective (see Chap. 5).

13.5 Conclusions

Project baseline scheduling, risk analysis and project control are crucial steps in the life of a project and are integrated under the dynamic scheduling label discussed throughout the various chapters of this book. 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 resource 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, offers an extra opportunity to increase the accuracy of the schedules and might serve as an additional tool to improve project control or tracking. Consequently, project scheduling and controlling 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 project metrics that quickly reveal information on time and cost deviations at the project level or the activity level. During control 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.

The purpose of this chapter was to give a brief summary of a large simulation experiment to test the contribution of two dynamic scheduling components – scheduling and risk analysis – on the efficiency of the third component (project control). The main contributions of the research study summarized in this chapter can be given along the following lines

- The research offers a comparative study to both academics and practitioners and provides an overview of and general results on EVM and SRA used during project performance measurement and project tracking.

- The research offers various project tracking and corrective action decision guidelines based on extensive simulation tests on a wide and diverse set of more than 4,000 fictitious projects. It distinguishes between top-down project tracking (EVM performance measurements as triggers at high WBS levels to drill down into lower WBS levels) and bottom-up project tracking (traditional activity based CPM project tracking, extended with project sensitivity information). Both tracking systems are used as trigger systems to warn for the need for corrective actions and their use highly depends on characteristics of the project.
- The research lays its main focus on the translation of general results to case-specific guidelines and rules-of-thumb, directly applicable to individual projects. Consequently, this makes the research a valuable tool for the project management discipline with great potential and a high practical value. In order to support this idea, a new software tool ProTrack has been developed, which contains all simulation results and allows the user to replicate the simulation experiment using their own data. This tool will be briefly discussed in Chap. 15.