Aalto-yliopisto
Insinööritieteiden korkeakoulu

Jari Pitkänen

Project Monitoring in Industrial Mechanical Installations

Thesis of diploma given in for the degree
of Master of Science in Technology.

Espoo 27.11.2017
Supervisor: Professor Kalevi Ekman
Instructor: Tomi Metsäniemi, Caverion Industria

Aalto-yliopisto, PL 11000, 00076 AALTO
www.aalto.fi

Diplomityön tiivistelmä

Tekijä Jari Pitkänen	
Työn nimi Projektin seuranta teollisuuden mekaanisissa asennuksissa	
Koulutusohjelma Konetekniikka	
Pää-/sivuaine Koneensuunnittelu	**Koodi** K3001
Työn valvoja Professori Kalevi Ekman	
Työn ohjaaja(t) Tomi Metsäniemi, Projektikontrollipäällikkö	
Päivämäärä 27.11.2017 **Sivumäärä** 79+13	**Kieli** Englanti

Tiivistelmä

Tämän työn tavoitteena on antaa Caverion Industrian Projektipalvelut -yksikölle kokonaisvaltainen käsitys Ansaittu arvo -menetelmästä ja laatia sen pohjalta ohjeistus menetelmän käyttöönottamiseksi asianmukaisella tavalla sekä kehittää työkalu kustannusten seurantaa ja ennustamista varten.

Ensiksi kirjallisuustutkimuksen avulla pohjustetaan kattava ymmärrys menetelmästä ja viimeisimmistä tutkimuksista. Toiseksi kirjallisuutta tarkastellaan menetelmän käyttöönoton ja harjoittamisen näkökulmasta. Kolmanneksi erityiset tarpeet määritetään yrityksen ohjeistuksen ja nykyisten käytäntöjen pohjalta.

Tulokset voidaan jakaa kahteen osaan. Ohjeistus asianmukaiseen mutta yksinkertaiseen käyttöönottoon on laadittu kirjallisuustutkimuksen ja nykyisten käytäntöjen arvioinnin pohjalta. Menetelmän johtamislähestymistapa luonnehditaan, tukevat analysointitekniikat kuvataan ja suosituksia Ansaittu arvo -menetelmällä johtamiseksi esitetään. Lisäksi Ansaittu arvo -työkalu on kehitetty yrityksen tarpeiden sekä kahden simulaatioilla ja laajalla empiirisellä aineistolla pätevöidyn teorian pohjalta.

Koska testaus ei kuulunut tämän työn laajuuteen, on suositeltavaa, että prosessit otetaan käyttöön, testataan ja työkalu pilotoidaan palautteen saamiseksi. Lisäksi työkalua tulee kehittää siten, että se mahdollistaa koontitilien yksityiskohtaisen analysoinnin, työn laajuuden muutoksien huomioinnin ilman rajoituksia sekä MS Project ja SAP -rajapintojen tehokkaan hyödyntämisen. Samoin suositellaan, että Earned Duration Management -menetelmää, Schedule Adherence -konseptia ja ennusteiden laadun arviointia tulisi harkita varteenotettavina laajennuksina Ansaittu arvo -menetelmän rinnalle, millä voitaisiin tuottaa lisäarvoa projektien kustannusten hallitsemiseksi.

Avainsanat Ansaittu arvo -menetelmä, käyttöönotto, projektin seuranta, kustannusten hallinta, suorituskyvyn mittaus, kustannusten ennustaminen

Aalto University
School of Engineering

Aalto University, P.O. BOX 11000, 00076 AALTO
www.aalto.fi

Abstract of master's thesis

Author Jari Pitkänen

Title of thesis Project Monitoring in Industrial Mechanical Installations

Degree programme Department of Engineering Design and Production

Professorship Engineering Design **Code** K3001

Thesis supervisor Professor Kalevi Ekman

Thesis advisor(s) Tomi Metsäniemi, Head of Project Controls

Date 27.11.2017 **Number of pages** 79+13 **Language** English

Abstract

The objective of this work is to provide comprehensive understanding of Earned Value Management methodology in order to formulate a rubric for proper implementation of the methodology and to develop a tool for monitoring and forecasting costs for Caverion Industria Project Services.

A comprehensive understanding of EVM methodology and state-of-the-art is founded by a careful review of related literature. Second, literature is being reviewed to provide assistance in implementing and practicing EVM. Third, the specific needs are confirmed by reviewing related company guidelines and assessment of current practices.

The results are twofold. First, a rubric for proper and simple EVM implementation has been established on the basis of literary research and assessment of current practice. The management approach is characterized, supporting analysis techniques described, and guidelines for managing with earned value provided. Second, an EVM Tool has been developed upon specific company needs and two methodologies that have been validated with large historical datasets, simulation experiments and withstood the test of time.

As the scope of this study did not include field-testing, it is suggested that the given processes shall be implemented and tested, and EVM Tool piloted for further feedback. Moreover, the tool shall be further developed to allow more detailed analysis of control accounts, consideration of scope changes without limitations and to enable efficient exploitation of MS Project and SAP interfaces. Similarly, implementation of Earned Duration Management, Schedule Adherence concept and assessment of forecasting quality in the EVM Tool as respectable extensions to add additional value in managing project costs shall be considered.

Keywords Earned Value Management, implementation, project monitoring, cost management, performance measurement, cost forecasting

Preface

This thesis was written for the benefit of Caverion Industria Project Services. First I would like to thank Vice President Pekka Alamattila for introducing me to this interesting topic and the opportunity to write this research. Second, I would like to thank my supervisor at Caverion Industria, Tomi Metsäniemi, Head of Project Controls, for his supervision, support and encouragement along the way. I am also especially grateful to my instructor Kalevi Ekman, Professor of Product Development at Aalto University, for his boundless inspiration, guidance and support.

I would also like to thank my colleagues at Caverion Industria, especially Project Managers Jukka Salonen and Arto Yppärilä, and Director of Sales and Marketing Mika Streng. Your guidance and support is very well appreciated. Also special thanks to Tuomas Lempiäinen and Sampo Valmunen for your support and proof-reading the text.

And above all I would like to express especial gratitude to my parents. Without your everlasting support I would not have been able to express myself by means of this paper.

Espoo 27.11.2017

Jari Pitkänen

Jari Pitkänen

Content

Abbreviations

AC	Actual Costs
AD	Actual Duration
AE	Apportioned Effort
AT	Actual Time
BCWP	Budgeted Cost of Work Performed, also referred to as earned value
BCWS	Budgeted Cost of Work Scheduled, also referred to as planned value
CaIn PS	Caverion Industria Project Services unit
CPI	Cost Performance Index
DEA	Data Envelope Analysis
EAC	Estimate at Completion
EAC(€)	Cost Estimate at Completion
EAC(t)	Time Estimate at Completion
ED	Earned Duration
EDM	Earned Duration Management
EDM(t)	Earned Duration Management method, also referred to as EDM
EQM	Earned Quality Management
ES	Earned Schedule
EV	Earned Value
EVM	Earned Value Management
EVMS	Earned Value Management System
ICCSM	Integrated CO2, Cost and Schedule Management
Jotbar	An automatic working time tracking system
LOE	Level of Effort
MPCS	Multi-dimensional Project Control System
OBS	Organization Breakdown Structure
QBS	Quality Breakdown Structure
PBEV	Performance-based Earned Value
PC	Personal Computer
PD	Planned Duration
PMB	Performance Measurement Baseline
PMI	Project Management Institute
PMO	Project Management Office
PV	Planned Value
NDT	Nondestructive Testing
SAP	Systems, Applications and Products in data processing
SAP PS	SAP Project System, a project management software module that integrates with other components of the SAP Enterprise Resource Planning (SAP ERP) system
SCI	Schedule Cost (Performance) Index
SCI(t)	Schedule Cost (Performance) Index based on earned schedule
SPI	Schedule Performance Index
SPI(t)	Schedule Performance Index based on earned schedule
SRA	Schedule Risk Analysis
SV(t)	Schedule Variance based on earned schedule

TCPI	To-Complete Performance Index
V10	Tailored financial management software used in Caverion Industria
VAC	Variance at Completion
WBS	Work Breakdown Structure
WDI	Welding Diameter Inch

1 Introduction

1.1 Background

Caverion Industria Oy Project Services (CaIn PS) is a unit responsible for large industrial mechanical installation projects. In unison with Caverion Industria Prefabrication Unit the Project Services provide total package deals or partial project execution from design to installation of mechanical entities. In large projects with several phases it is material for the project management to be able to reliably plan, monitor and forecast the project progress and the corresponding actual costs as they are being incurred. This has proven to be challenging, especially for two reasons: tendency of changes in large projects and lack of common practice.

First, large projects in general involve at least four parties: customer, supplier, designer and contractor. Depending on the size of the project there are many contractors involved as well as subcontractors. Customer defines the delivery; the quality and schedule of the product. When everything goes as planned, forecasting is relatively easy. However, large scale complex projects tend to face number of changes, or problems, which may further affect the schedule and costs. It is rather common that the effects on schedule accumulate towards the end, and hence it is the contractor, such as CaIn PS, that has to deal with the changes. When changes are involved, predicting progress, income and costs is more challenging.

Second, Caverion Industria Oy Project Services is a large unit with several project managers with different backgrounds, and each of them has they own ways of working. The execution of work has been in the center of the focus rather than project management. When it comes to economics, some broad guidelines exist but they have allowed much freedom for the project managers in reporting and forecasting based on their own experience. Now the problem is when various practices exist that the numbers may not be transparent and comparable which further complicates the economical predictability of the unit for the management. These kinds of issues in relation to cost management are not exceptional since poor cost performance of construction projects seems to be the norm rather than exception (Baloi, Price 2003).

1.2 Problem, Objective and Research Questions

For long have the project managers practiced their own ways to deal with project cost management. Indeed, with various different practices to monitor and forecast costs in projects, it has been challenging for the management to reliably monitor and forecast the costs. Inconsistency causing unreliability in monitoring and forecasting costs has been identified as a major issue. However, the core of the issue lies far beneath the cost monitoring and control.

The Caverion Industria organization is at the moment under reconstruction. The emphasis of project work has merely been in the executing end of the project. However in today project execution and different requirements the execution-centered way of constructing the project organization has come to an end. As the requirements of projects have changed, more attention is needed in the project management itself. Hence, the intention now is to go towards matrix organizational structure, meaning there is dual managerial accountability and responsibility. To be exact there would be two chains of command: the functional line and the project line. Consequently there would be a distinct project management office (PMO) and site execution unit. The primary objective of this arrangement is to increase the project management maturity. It has also been determined that the project management office shall include a unit or a team responsible for project planning, monitoring and control. From now on we shall refer to this as the *control team*. In the big picture, the idea is to provide and equip this control team with set of processes and tools to be able to deal with planning, monitoring and controlling of the projects and help the project manager in managing the project.

As stated above, the concern had emerged from unreliability in monitoring and forecasting costs. However, to be able to reliably monitor progress and further costs, it is material to have a strong foundation to build on. Now to fix this issue we are to produce a consistent practice for monitoring and forecasting costs to help the control team in monitoring and forecasting the costs reliably. For this purpose Caverion Industria management has chosen to introduce Earned Value Management (EVM) methodology. Hence, the objective is to establish the foundation for EVM practice and to produce a tool for the control team wherein they can enter project data, and as an output have consistent metrics and forecasts on project costs.

Now to conclude, the objective of this work is to provide comprehensive understanding of Earned Value Management methodology and develop an EVM Tool for the control team for monitoring and forecasting costs. Although cost management processes are bound to scope and time management processes, they are not in the core of this study but rather cost management is considered as a separate entirety. Scope and time management are covered to the extent necessary to provide proper understanding of the broader picture of which earned value management relates.

Now having a critical review of the background and objectives of the work, the research questions to be answered by this study are as follows:

1. How to enable proper cost monitoring and control of projects with Earned Value Management?
2. What are the state-of-the-art methods to practice EVM?
3. How to enable consistent and reliable forecasting with help of an EVM Tool?

1.3 Research Process

In Caverion Industria Project Services (CaIn PS) does not have earlier experience of EVM and now is about to implement this methodology. Hence, it is material to provide comprehensive review of earned value management and related issues to allow proper understanding of the topic and development of the tools necessary. Further, to avoid the early adaptation problems and have desirable results from the beginning, it would be material to identify the prerequisites for successful implementation of EVM. Thus, literature in relation to implementation of EVM shall be analyzed.

Earned Value Management is universal methodology for cost management. The basis of the methodology lies on the fact that past patterns and trends are indicative of future conditions. This methodology helps to see clearly and objectively where the project is and where it is headed compared to where it was supposed to be and where it was supposed to be going. The traditional model has been known for years but researchers are striving to improve and produce more accurate models for more precise results and predictions. The present trends in EVM development will be studied and potentially applied to complement the traditional model. Similarly there exist good practices and common pitfalls when it comes down to application of EVM. A lot of experience in EVM usage has potentially highlighted some useful guidelines to achieve better results with the system which shall be reviewed.

In order to develop better practices, it is necessary to first draw a map of the current situation. The project guidelines and supporting infrastructure in relation to cost management will be examined. Particular emphasis will be placed on an internal code of practice referred to as Project Handbook (*Projektikäsikirja* in Finnish) and discussions with management to construct the general view of current practice

Finally to answer the research questions, the plan is to first provide a comprehensive understanding of EVM methodology and the state-of-the-art by careful review of related literature. Second, the literature will be reviewed to provide assistance in implementing and practicing EVM as part of cost management. Third, to be able to tailor the outcome for Caverion Industria, the specific needs will be confirmed by reviewing related company guidelines and as per discussions with Caverion Industria management. Lastly, on this basis, an EVM Tool will be developed as the core of the EVM practice to facilitate the control team in performance measurement and forecasting.

2 Literature Review

The primary objective of this study is to provide a consistent method for cost monitoring and forecasting by means implementing the EVM methodology and developing a complementary tool. However, to be able to develop and implement such a tool, it is of utmost importance to first gain understanding of Earned Value concept. The following sections will focus on describing the context and theoretical basis of Earned Value Management. First of all, the role of earned value management as part of the project management process will be described. Secondly, theoretical basis developed by U.S. Department of Defense (DoD) will be described to the appropriate extent. As the theoretical basis has been provided, recent significant developments and extensions to EVM theories will be described and later complemented with a summary of the state-of-the-art of EVM research. Last, useful guidelines in use and implementation of EVM will be provided.

2.1 Earned Value Management

Objective of this section is to provide general understanding of EVM in context of project management. The section is twofold. First, the role of earned value management will be described in relation to project management. Second, earned value management will be considered as part of the project management process.

2.1.1 Role of Earned Value Management

Feedback is of the essence to the success of any project. Identification of problems usually hinges upon timely and targeted feedback which allows making adjustments to keep a project in time and budget. Indeed, EVM has been acknowledged as one of the most effective tools for project performance measurement and feedback. It effectively allows managers to close the loop in the plan-do-check-act management cycle. (PMI 2005, p. 1)

EVM methodology helps to see, clearly and objectively, where the project is and where it is headed compared to where it was supposed to be and where it was supposed to be going. Therefore it has also been referred to as “management with lights on”. The fundamental principle behind EVM is that patterns and trends in the past are good indicators of future performance. (PMI 2005, p. 1)

Earned Value Management provides organizations with a framework which integrates the management of the project management triangle elements: scope, schedule and cost. EVM can assist in answering some of the key project management questions which are considered critical to the success of every project. (PMI 2005, p. 1) These questions are as follows (PMI 2005, pp. 1, 16):

1. Are we ahead or behind schedule?
2. How efficiently are we using time?
3. When is the project likely to be completed?
4. Are we currently under or over our budget?
5. How efficiently are we using our resources?
6. How efficiently must we use our remaining resources?
7. What is the remaining work likely to cost?
8. What is the entire project likely to cost?
9. How much will we be under or over budget at the end?

In the event the use of EVM to a project reveals that the project is behind schedule or over budget, EVM can assist the project manager in further analysis and help to identify:

- Where problems are occurring,
- Whether problems are critical or not, and
- What will it take to get the project back on track.

2.1.2 Earned Value Management as Part of Project Management Process

Earned Value Management, as a practice, is part of a complex referred to as project management. EVM in itself does not make beatific but requires application of good project management principles to be used effectively. Hence, it is important to examine the role and relations of EVM in effective project management. (PMI 2005, p. 2)

Project management is mainly about planning, executing, and controlling the work. The areas of project management to which EVM is fundamentally most applicable are indicated in Figure 1.

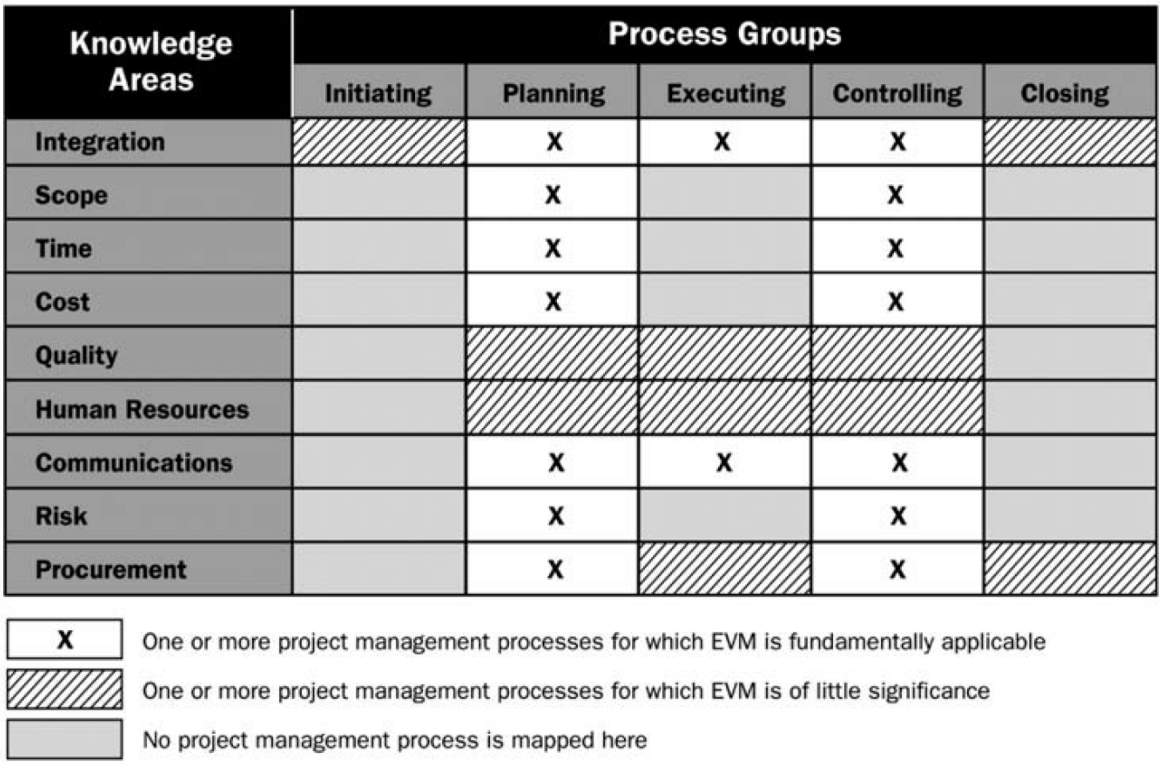


Figure 1. Role and relations of EVM in project management as suggested by PMI (2005, p. 2)

Project planning chiefly involves determination of the following (PMI 2005, p. 2):

- Work to be performed (scope) and its elements (work breakdown structure)
- Who is going to perform and manage the work (responsibility assignment matrix)
- When the work is to be done (schedule), and
- How much labor, materials, and related resources are required to complete the work (cost).

Project execution, on the other hand, is primarily a matter of performing the work and keeping the stakeholders informed. Last, project control generally involves monitoring and reporting the execution of project management plans related to scope, schedule, and cost, along with quality and risk. That is, project control is a process which aims to maintain the performance and results within an acceptable range of the work plan. (PMI 2005, p. 2) The project control process is illustrated in Figure 2.

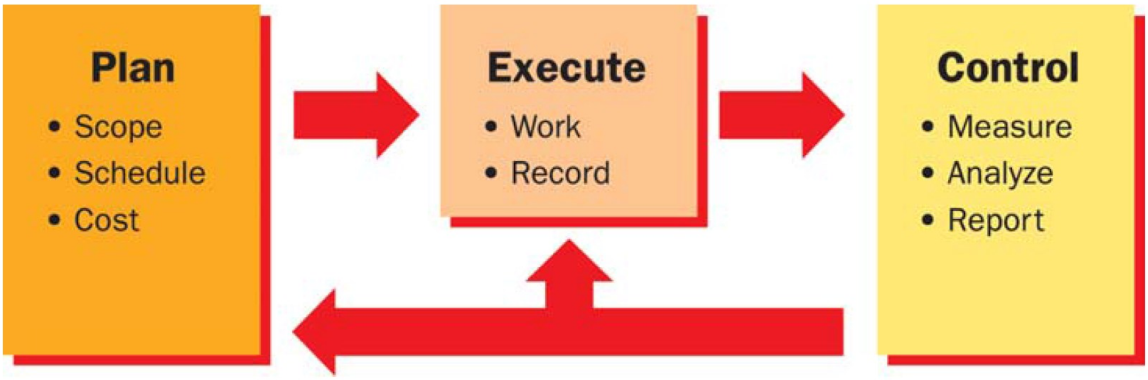


Figure 2. EVM and the project management process (PMI 2005, p. 2)

In regards of the project planning process, EVM requires establishment of a performance measurement baseline (PMB). Therefore good project planning principles, especially in relation to scope, schedule and cost, are of importance. Similarly, employment of EVM emphasizes the need of executability and manageability of project work, and responsibility and accountability of assigned workers and managers for project's performance. (PMI 2005, p. 3)

In order to assign and manage the work, the project needs to be broken down, by means of a work breakdown structure (WBS), into executable tasks and manageable elements referred to as control accounts (CA). Management responsibility of each discrete element is assigned to one individual or a team. An organizational breakdown structure (OBS) can be used to assist in assigning the work for execution. (PMI 2005, p. 3)

A logically scheduled and resourced work plan enables project monitoring. A competent work plan requires a time-phased budget also referred to as performance measurement baseline which integrates and records the scope of work, schedule, and costs. (PMI 2005, p. 3) Similarly, earned value measurement techniques must be determined for each work task. Selection of appropriate techniques shall be based on scope, schedule, and cost considerations. (PMI 2005, p. 4)

In order to enable comparison with the performance measurement baseline, during project execution, the assigned resources have to be recorded for work performed in each element included in the project management plan. (PMI 2005, p. 4)

Last, within the project control process, EVM requires assessment of physical work progress and crediting of budgetary earned value with selected earned value measurement techniques. The EVM analysis can be finally performed at the control account and other levels of WBS with the produced earned value data, planned value data, and actual cost data, and EVM results can be further reported. (PMI 2005, p. 5) The relationship between WBS, OBS and control accounts is presented in Figure 3.

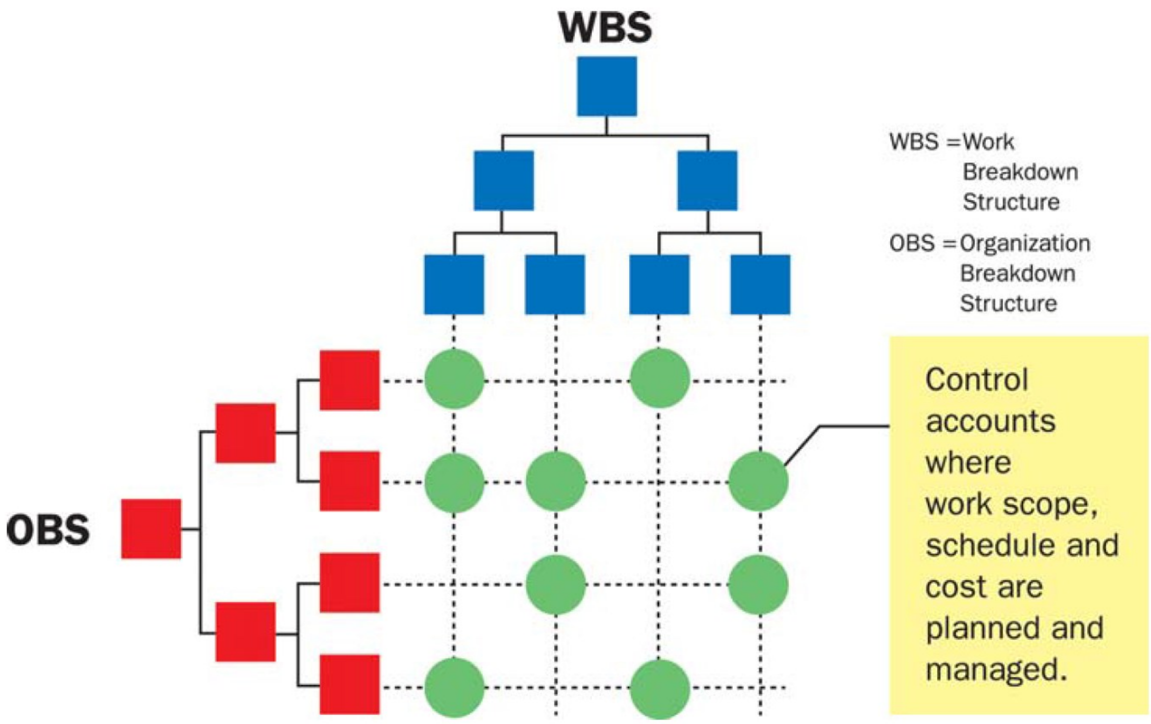


Figure 3. Control account matrix (PMI 2005, p. 3)

In conclusion, implementation of EVM inherently supports effective project management in facilitating the planning and control of cost and schedule performance (PMI 2005, p. 6). As per PMI (2005, p. 6), the key practices to enable effective use of EVM include:

- Establish a performance measurement baseline:
  - Decompose work scope to a manageable level
  - Assign unambiguous management responsibility
  - Develop a time-phased budget for each work task
  - Select earned value measurement technique for all tasks
  - Maintain integrity of PMB throughout the project.
- Measure and analyze the performance against the baseline:
  - Record resource usage during project execution
  - Objectively measure the physical work progress
  - Credit earned value according to earned value techniques
  - Analyze and forecast cost and schedule performance
  - Report performance problems and take action.

2.2 The Traditional Method

2.2.1 Earned Value Management as a Concept

Although earned value management has been introduced long time ago, only on last three decades it has begun to gain wider acceptance. First introduced as a part of the failed U.S. Department of Defense's PERT/Cost system, it was not until the more successful Minuteman program that it was incorporated in a U.S. DoD project management specification that detailed Cost/Schedule Control Systems Criteria (C/SCSC). However, wrapped up in a logical but bureaucratic management process required by DoD, not many made the distinction between the earned value accounting and measurement principles and the complete program it was featured in. (Webb 2003, p. 2) The PC revolution, a break from earlier standalone systems allowing the integration with other company systems enabled the recognition of earned value measurement as a process integrating planning and accounting systems (Webb 2003, pp. 2-3). Hence project managers equipped with suitable planning software packages could employ earned value performance measurement as a valuable project control tool suitable for oneself. The earned value had finally 'came of age'. (Webb 2003, p. 3)

Generally earned value methods can be used for any project (Webb 2003, p. 3). However, suggesting that the approach is equally applicable for all types of projects would not be reasonable. Projects that possess most or all of the following characteristics are well suited by earned value methods (Webb 2003, p. 3):

- A clearly defined objective
- A clearly cognizable route to goal
- Extended period of working
- Labor intensive
- Tasks of creative nature
- Management structure is formalized, and
- Limitations in cost and time.

An engineering development work by example is an ideal application, and where the earned value concept was also first used (Webb 2003, p. 3).

Now assuming that earned value methods are being applied, what is to be expected? At the time of introduction, the stakeholders anticipated better insight into the progress of their projects costwise and schedule-wise (Webb 2003, pp. 5-6). The situation has not changed. It is now as important to have a clear view of the project performance and direction as it was 40 years ago. (Webb 2003, p. 6) The importance of earned value is featured in various ways (Webb 2003, p. 6):

- Early warning signal allows for change in a deteriorating situation before it is too late.
- Accurate forecasting enables better decision making regarding 1) the course of the project and 2) external matters which may be influenced by the progress of the project.
- Stakeholder confidence is improved by open and verifiable view of the project.

Further implementation of earned value methods places emphasis on effective planning, costing and monitoring systems which can improve overall project management. Figure 4 presents some benefits associated with earned value methods as seen in a survey carried out in the UK among users of earned value methods. However, the benefits come at a price. (Webb 2003, p. 6)

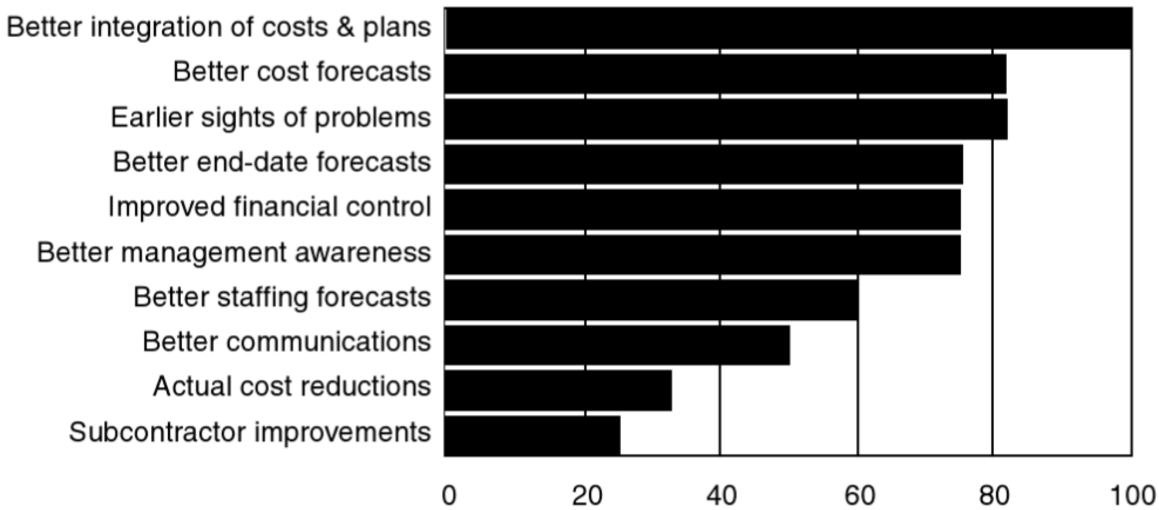


Figure 4. Benefits associated with earned value methods as per a British survey (Webb 2003, p. 6)

It is no doubt that introduction of such methodology in a project environment may inflict serious complications. The implementation may call for changes in operating practices, such as greater discipline in planning processes, greater emphasis on objective reporting, improved integration between the planning systems and the accounting systems, and even implementation of a new software. Growing pains in introducing a new approach are most likely inevitable but well worth having them. (Webb 2003, p. 7)

The following section will present the terminology and methodology of earned value management.

2.2.2 Earned Value Management Methodology

Earned Value Management is a methodology used to measure and communicate the progress of project. This is performed through integration of time, cost and scope into a single project management and control system. The work completed, the time taken and the costs incurred to complete the project are considered in order to facilitate evaluation and control of project risks by measuring project progress in monetary terms. (Vanhoucke 2014, p. 17) Vanhoucke (2014, p. 17) describes an EVM system as follows:

*"An EVM system consists of a set of metrics and formulas that can be divided into three categories. Three **key metrics** will be used to assess the progress of the project as calculated by the **performance measures** and eventually **forecasting methods** will then translate these performance measures into predictions about the expected final time or cost objectives of the project." (emphasis added)*

So EVM builds upon three input parameters, referred to as key metrics. Each of the key metrics represents different cost values for each activity and can be summed up to the project level. They are used to calculate performance of a project at hand and further to produce predictions of future. Values of the key metrics shall be collected on regular basis for monitoring and control purposes. (Vanhoucke 2014, p. 18)

The three key metrics are:

- The Planned Value (PV) – the budget baseline over time reflecting the baseline schedule. It shows the progression of budgeted activity cost considering the activity start and finish times in the baseline schedule. The planned value is traditionally referred to as the Budgeted Cost of Work Scheduled (BCWS). (Vanhoucke 2014, p. 18)

- The Actual Cost (AC) – cumulative actual expenditure spent at a given point in time. Naturally the actual cost shall correspond only to the costs incurred in accomplishing the planned work. (PMI 2008, p. 182; Vanhoucke 2014, p. 20) Also referred to as the Actual Cost of Work Performed (ACWP) (Vanhoucke 2014, p. 20).
- The Earned Value (EV) – the budgeted value of real physical progress accomplished at given point in time. Earned value is traditionally referred to as the Budgeted Cost of Work Performed (BCWP). (Vanhoucke 2014, p. 20) EV is calculated as follows (Vanhoucke 2014, p. 20):

$$EV = PV \times Physical\ progress\ (\%). \tag{1}$$

All of the above metrics shall be monitored both incrementally and cumulatively; incrementally to determine the current status, and cumulatively to determine the long-term performance trends. (PMI 2008, p. 182) A typical S-curve of the three key metrics is presented in Figure 5.

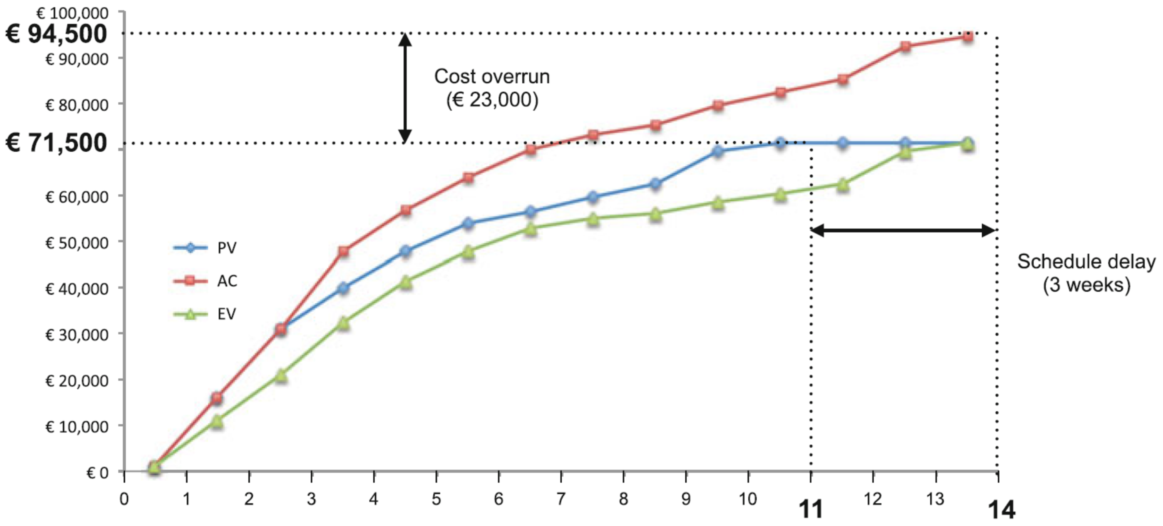


Figure 5. A typical S-curve with the three EVM key metrics (Vanhoucke 2014, p. 19)

The planned value shows the cumulative cost increase as proposed by the baseline schedule. The baseline schedule acts as the benchmark during all measurement and forecasts and, hence, construction of the schedule is key to success in controlling the project. If possible, the baseline schedule should be kept intact throughout the lifetime of the project. However, dramatic deviations from the original baseline schedule may require consideration of re-baselining which would reset the benchmark for future project control. (Vanhoucke 2014, pp. 18-19)

The performance is measured by means of variance analysis and set of performance indices. The performance measures provide information on the current time and cost objectives compared to the baseline schedule, and further allows for detection of early warning signal and trigger to take corrective action. (Vanhoucke 2014, p. 22)

The time performance is measured with two metrics: the Schedule Variance (SV) and the Schedule Performance Index (SPI). Both metrics measure the deviation between the value of the work done (EV) and value of the work planned (PV) at given moment. Whereas the schedule variance expresses the time performance as an absolute value in monetary units, the schedule performance index presents the performance as a percentage of the expected baseline schedule performance. (PMI 2008, pp. 182-183; Vanhoucke 2014, p. 22)

Similar to time performance, the cost performance is measured with two metrics: the Cost Variance (CV) and the Cost Performance Index (CPI). Both metrics measure the deviation between the value of the work done (EV) and actual cost (AC) at given moment. The cost variance is measured in absolute monetary units whereas the cost performance index conveys the cost performance as a percentage of the expected baseline cost performance. (Vanhoucke 2014, p. 26) For the sake of comprehensiveness, the formulas for performance variances and indices are summarized below (see formulas (2-(5). The performance measures provide valuable information for the decision making during project control in determining whether actions are necessary (Vanhoucke 2014, p. 28).

Time performance formulas for schedule variance (SV) and schedule performance index (SPI) are as follows (Vanhoucke 2014, p. 22):

$$SV = EV - PV, \tag{2}$$

where < 0: project behind schedule
= 0: project on schedule
> 0: project ahead of schedule,

and

$$SPI = \frac{EV}{PV}, \tag{3}$$

where < 1: project behind schedule
= 1: project on schedule
> 1: project ahead of schedule.

Cost performance formulas for cost variance (CV) and cost performance index (CPI) are as follows (Vanhoucke 2014, p. 25):

$$CV = EV - AC, \tag{4}$$

where < 0: project cost over budget
= 0: project cost on budget
> 0: project cost below budget,

and

$$CPI = \frac{EV}{AC}, \tag{5}$$

where < 1: project cost over budget
= 1: project cost on budget
> 1: project cost under budget.

An interpretation matrix of basic EVM performance measures is presented in Figure 6.

Performance measures		Schedule		
		SV > 0 & SPI > 1.0	SV = 0 & SPI = 1.0	SV < 0 & SPI < 1.0
Cost	CV > 0 & CPI > 1.0	Ahead of Schedule Under Budget	On Schedule Under Budget	Behind Schedule Under Budget
	CV = 0 & CPI = 1.0	Ahead of Schedule On Budget	On Schedule On Budget	Behind Schedule On Budget
	CV < 0 & CPI < 1.0	Ahead of Schedule Over Budget	On Schedule Over Budget	Behind Schedule Over Budget

Figure 6. Interpretation matrix of basic EVM performance measures followed by PMI (2005, p. 16)

The performance metrics can now be used in forecasting the expected final project objectives. On the basis of currently known and expected performance, the forecasting methods are employed to predict the expected project time and cost. The PMI Practice Standard for Earned Value Management presents the following cost related forecasts (PMI 2005, p. 15):

- Estimate to Complete (ETC),
- Estimate at Completion (EAC),
- Variance at Completion (VAC), and
- To-Complete Performance Index (TCPI).

The estimate at completion can differ from the budget at completion based on the project performance. It is calculated as the sum of actual costs (AC) and estimate to complete (ETC) (PMI 2008, p. 184). Hence (PMI 2008, p. 184):

$$EAC = AC + ETC. \tag{6}$$

The ETC can be estimated manually (by means of bottom-up estimation) or calculated in different ways as linear extrapolations of current of current tendencies (Czarnigowska 2008; PMI 2008, p. 184). Considerations regarding the to-date and expected future performance governs the choice of the forecast (PMI 2008, p. 184). If both SPI and CPI are considered, weighing of CPI and SPI should be done as per project manager's judgement. (PMI 2008, p. 185) The generic formula is as follows (Vanhoucke 2014, p. 63):

$$EAC = AC + \frac{BAC - EV}{PF}, \tag{7}$$

where PF is the performance factor. The four of the more common methods are ETC formula based on budgeted rate (8), present CPI (9), present SPI and CPI (10), and present SPI and CPI weighed (11) (PMI 2008, p. 185). The formulas are summarized below (PMI 2008, p. 185):

$$EAC_1 = AC + BAC - EV, \tag{8}$$

$$EAC_2 = \frac{BAC}{CPI}, \tag{9}$$

$$EAC_3 = AC + \frac{BAC - EV}{CPI \times SPI}, \tag{10}$$

and

$$EAC_4 = AC + \frac{BAC - EV}{\alpha \times CPI + \beta \times SPI}, \tag{11}$$

where α + β = 1. A graphical illustration of cost forecasting (EAC_2) based on CPI is presented in Figure 7.

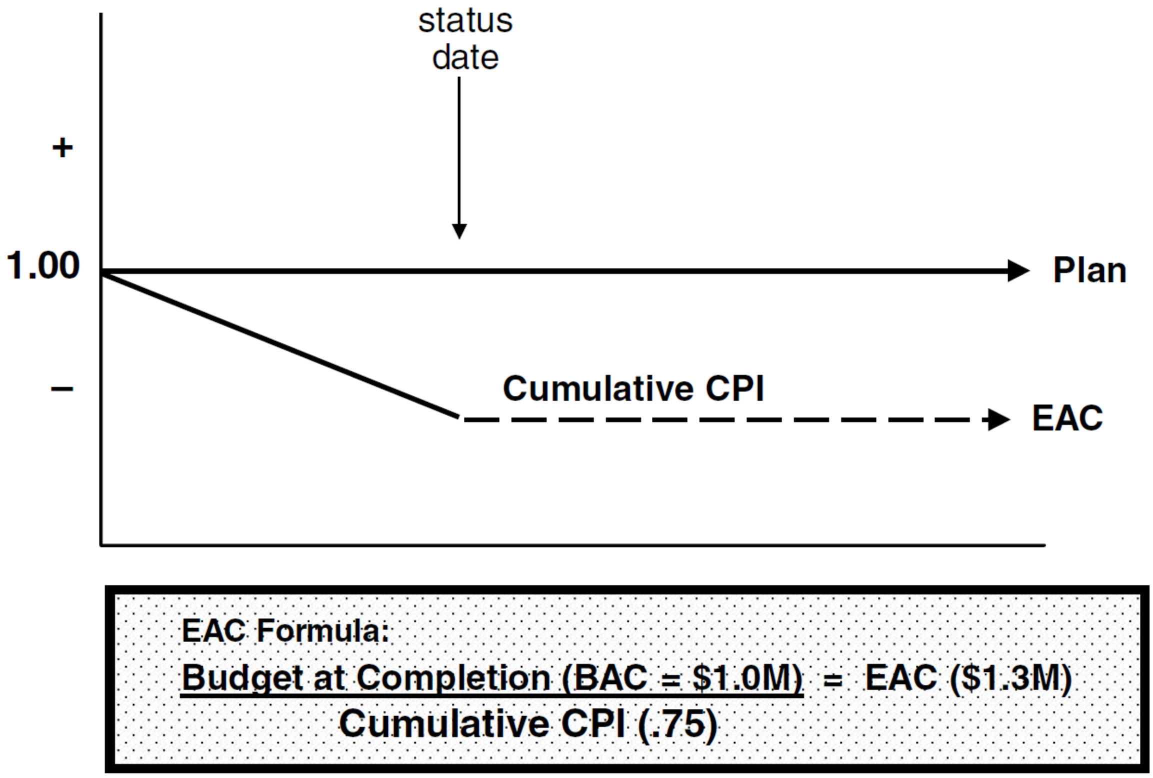


Figure 7. Illustration of cost forecasting (EAC_2) based on CPI by means of linear extrapolation (Fleming, Koppelman 2007)

Although other forecasts in relation to EVM exist, they are not associated with standard EVM practice, and will be discussed later.

Variance at Completion (VAC) describes the projected deviance from the budget (BAC) considering the predicted EAC (PMI 2005, p. 19):

$$VAC = BAC - EAC. \tag{12}$$

The To-Complete Performance Index (TCPI) projects the cost performance to be achieved for the remaining work to meet the target, BAC or EAC (PMI 2008, p. 185). The formulas with targeted BAC and EAC respectively are as follows:

$$TCPI(BAC) = \frac{BAC - EV}{BAC - AC}, \tag{13}$$

and

$$TCPI(EAC) = \frac{BAC - EV}{EAC - AC}. \quad (14)$$

The Time Estimate at Completion (EAC_t) is a time related counterpart for the cost EAC. As is for the cost counterpart, Time Estimate at Completion can differ from the planned duration based on the project performance. (PMI 2005, p. 17) This rough time estimate is calculated on the basis of SPI as follows (PMI 2005, p. 17):

$$EAC_t = \frac{BAC/SPI}{BAC/PD} = \frac{PD}{SPI}, \quad (15)$$

where PD is the planned duration. However, it shall be noted that this is a fairly rough estimate. Further it is suggested that time-based schedule methods such as critical path method are used for time forecasting since earned value analysis does not account for criticality and interdependencies of tasks. (PMI 2005, p. 17) The issues in relation to EVM time forecasting are elaborated in Sections 2.2.4 and 2.3.1.

The presented EVM metrics, performance measures and forecasts are summarized in Figure 8.

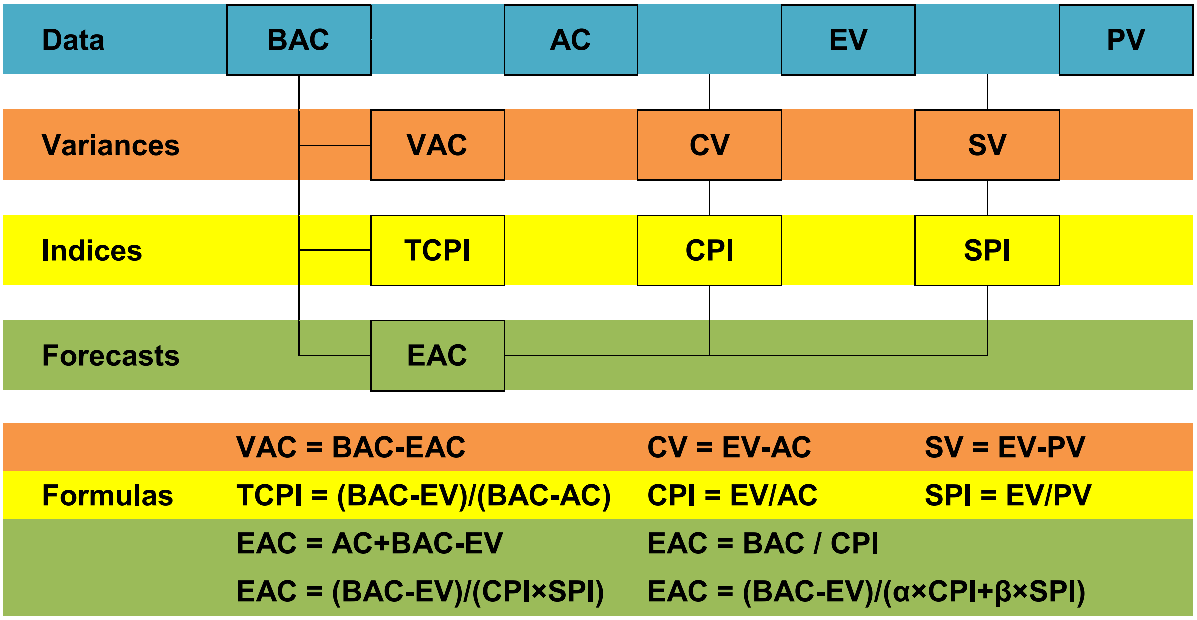


Figure 8. EVM metrics, performance measures and forecasts followed by PMI (2005, p. 16; 2008, p. 185)

Finally to close the loop, what is the fundamental value in context of project management that the presented EVM performance measures and forecasts essentially provide? They answer the critical project management questions stated in Section 2.1.1. (PMI 2005, p. 1) The linkage between the project management questions and performance measures and forecasts is provided in Table 1 (PMI 2005, p. 16).

Table 1. Linkage between critical project management questions and EVM measures followed by PMI (2005, p. 16)

Project Management Question	EVM Performance Measure	Formulae
How are we doing time-wise?	**Schedule Analysis & Forecasting**	
Are we ahead or behind schedule?	Schedule Variance (SV)	(2)
How efficiently are we using time?	Schedule Performance Index (SPI)	(3)
When are we likely to finish work?	Time Estimate at Completion (EAC_t)	(15)
How are we doing cost-wise?	**Cost Analysis and Forecasting**	
Are we under or over our budget?	Cost Variance (CV)	(4)
How efficiently are we using our resources?	Cost Performance Index (CPI)	(5)
How efficiently must we use our remaining resources?	To-Complete Performance Index (TCPI)	(13-14)
What is the project likely to cost?	Estimate at Completion (EAC)	(7-11)
Will we be under or over budget?	Variance at Completion (VAC)	(12)
What will the remaining work cost?	Estimate to Complete (ETC)	(7-11)

2.2.3 Managing with Earned Value

Earned Value Management is fundamentally a management-by-exception approach. That is, invoking of control actions is necessary only when significant or predetermined deviations to the baseline are being noted. It allows the managers to primarily focus on project execution which greatly contributes to the efficiency and effectiveness of project management. Combined with WBS, the EVM performance measures provide the objective data necessary to management-by-exception. (PMI 2005, p. 20)

EVM can be used to establish acceptable levels of performance for a project and its tasks. An organization can set project specific thresholds e.g. by means of variance percentages or performance measures. Hence, no management action would be taken until the predetermined measures fall outside of acceptable range. A negative variance may be an indication of a problem whereas a positive variance may represent an opportunity. (PMI 2005, p. 20)

As for the EVM calculations, management-by-exception should occur first at the task level where the scope, schedule, and scope of work are planned and controlled. Performance measures shall be used by the managers to determine whether the action thresholds have been reached for their tasks and control accounts. (PMI 2005, p. 20) Management-by-exception can be then used on any level of the project through simple summation of WBS elements (PMI 2005, p. 21).

In addition to overall variances and performance thresholds, potential performance problems can be deciphered or anticipated through trends in performance measures. Cumulative performance or variance can be on acceptable range but also trending down towards efficiency threshold for several review periods which could be a cause for some concern or need examination to identify the underlying cause. With help of a WBS higher level trends can be drilled down to lower levels to further analyze the underlying cause. Trend analysis, especially, can be facilitated with use of graphs plotting the performance measures over time. (PMI 2005, p. 21)

The objective of EVM is better cost and schedule performance in accomplishment of work. Although EVM data is useful in analyzing the project performance, it does not reveal the causes of performance. (PMI 2005, p. 25) Ultimately it is subject to project manager's and project team's judgement to decide where the problems lie and what actions to take or recommend. It is of utmost importance that EVM provides the best possible feedback for those making the decision and taking action. Simple metrics alone are usually not enough but a comprehensive understanding should be built on the basis of graphs and tables representing patterns and trends in periodic and cumulative data, complemented with explanations and interpretations provided by the managers having the best information and insight. (PMI 2005, p. 26)

2.2.4 Considerations

Earned value management, when applied appropriately, is a very useful methodology to assist in cost management. However, quite recently, various researchers have raised questions regarding some areas of EVM. Particularly the simplicity of time performance metrics has been highlighted to be of concern. (Vanhoucke 2014, p. 25)

Two issues reported by Lipke (2003) stems from the foundation of the methodology. The earned value methodology is based on the three key metrics that are all expressed in monetary units. This means that all the performance metrics are based on real costs (AC) and planned costs (PV) that should have been made for the work done (EV). Evidently for the cost performance metrics this does not constitute an issue. However, for the time performance metrics this can be misleading, and lead to confusion and misinterpretations. (Vanhoucke 2014, p. 25)

First, the schedule variance, i.e. the time difference between planned work and work done is expressed in monetary units. This might well give the false impression that the time performance metrics can be used for cost performance reporting. The EV is expressed as percentage of the planned value and, hence, does not necessarily relate to real costs. It is only indicative of the ideal planned timing for the current value earned. (Vanhoucke 2014, p. 25)

Second, quirky behavior has been noted for time performance metrics towards the end of the project. The reason lies in SV and SPI formulas. EV represents the earned fraction of the BAC. When project finishes, EV = BAC regardless of if it is ahead, in time or late. Consequently, SV = PV-EV = 0 and SPI = EV/PV = 1 = 100% indicating a perfect on-time project schedule. (Vanhoucke 2014, p. 26, 35) Vanhoucke (2014, p. 26) has reported this SPI's unreliable trend towards 1 to start already at 50-60% project completion. This unreliable trend always occurs for projects ending late. For projects finishing in time or early, such behavior cannot be observed. This trend was first formally described by Lipke (2003), and he has further proposed an alternative time performance system to overcome this behavior, the Earned Schedule Management (ESM). This extension to EVM will be further discussed in Section 2.3.1 Earned Schedule.

2.3 Present Trends in Earned Value Management

Earned value management has history of several decades as a tool for cost management. However, the extensive use and research efforts in relation to the traditional method have identified several pitfalls that have left room for further development and introduction of enhanced methodologies. The focus of the following is to introduce methodologies that attempt to extend the theory of earned value in order to enable better cost management.

Starting from the more common extensions, this section will provide an extensive review of the present trends in earned value methodology development, validation of forecasting methods, state-of-the-art theories, recognized considerations in relation to earned value methodology in general and identified trends of future research efforts.

2.3.1 Earned Schedule

Earned Schedule methodology is an extension to EVM theory developed by Walt Lipke (2003). The concept is analogous to that of earned value, with the exception that instead of cost, time is being used for measuring schedule performance (Lipke 2003). The concept was developed in order to overcome the quirky behavior of time performance metrics already observed in early EVM studies and later formally described by Lipke (2003).

The idea of earned schedule is simple; time should be used for measuring schedule. The Earned Schedule (ES) metric is the translation of EV expressed in monetary units into a metric expressed in time units. The periodic ES value is obtained by the ES metric connecting the periodic EV measured during project progress to the PV curve. (Vanhoucke 2014, p. 35-36) Hence, extra input other than the three key metrics (EV, PV, AC) is not necessary and the extension can be easily adopted by anyone familiar with traditional EVM methodology (Vanhoucke 2014, p. 36).

The EV line expresses the earned increase of the project value over time (Vanhoucke 2014, p. 36). The ES is found by projecting the EV onto PV curve (Lipke 2003; Vanhoucke 2014, p. 36-37). That is, ES is the time point where the EV at the current review period, i.e. actual time (AT), is equal to the PV value on the PV curve (Vanhoucke 2014, p. 36). ES can be determined as follows (Vanhoucke 2014, p. 36):

Find such t that $EV \geq PV_t$ *and* $EV < PV_t + \Delta t$

$$ES = t + \frac{EV - PV_t}{PV_{t+\Delta t} - PV_t} \Delta t, \tag{16}$$

where ES is the Earned Schedule, EV is the Earned Value at AT, PV_t is the Planned Value at time instance t, and $PV_{t+\Delta}$ is the Planned Value at time instance t+Δ. A graphical illustration of this linear interpolation between PV_t and PV_t+Δ is presented in Figure 9.

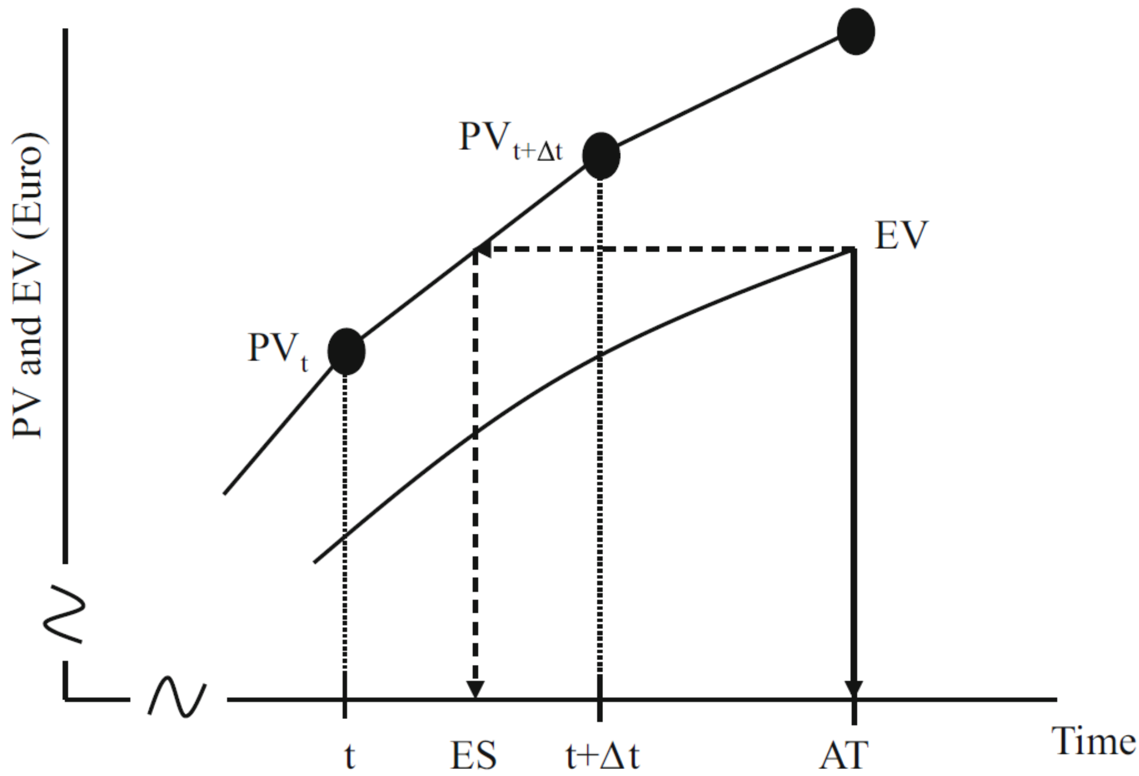


Figure 9. Linear interpolation between PV_t and $PV_{t+\Delta}$ (Vanhoucke 2014, p. 37)

As the EV metric has maximum value of BAC at the end of the project, equivalently ES has a maximum value of planned duration (PD). Hence, at project finish, EV = BAC and ES expresses the time point where the EV value should have been obtained, that is, the expected planned duration. (Vanhoucke 2014, p. 37)

Now that ES is an alternative metric for performance measurement, it has also alternative associated performance measures (Vanhoucke 2014, p. 38). These alternative performance measures Schedule Variance SV(t) and Schedule Performance Index SPI(t) are calculated at each review period as (Vanhoucke 2014, p. 38):

$$SV(t) = ES - AT, \tag{17}$$

where < 0: project behind schedule
= 0: project on schedule
> 0: project ahead of schedule,

and

$$SPI(t) = {}^{ES}/_{AT}, \tag{18}$$

where < 1: project behind schedule
= 1: project on schedule
> 1: project ahead of schedule.

Now acknowledging the linkage of ES and EV metrics, and seeing the formulation of SPI(t), it is evident that the SPI(t) calculation at a certain review period AT is totally analogous to its SPI calculation (Vanhoucke 2014, p. 38). Moreover, Vanhoucke (2014, p. 38) states that the following holds for a project in progress at the current point in time AT:

"EV = value earned at AT for the work done expressed in a monetary unit

ES = time earned at AT for the work done expressed in a time unit

and

PV = work planned at AT expressed in a monetary unit

AT = the amount of time the project is in progress",

and continues:

"Based on the similarities between EV and ES and PV and AT, respectively, the calculation of SPI = EV/PV can be replaced by its time based alternative SPI(t) calculated as ES/AT."

Hence, the SPI(t) performance measure constitutes a valid substitute for the original SPI (Vanhoucke 2014, p. 38). And more importantly, the SPI(t) indeed does not show the aforementioned quirky behavior towards the end of the project, and is therefore much more reliable (Vanhoucke 2014, p. 38-39). Further in relation to duration forecasting, Vanhoucke (2014, p. 40) has shown that ES metrics outperform the traditional EVM metrics when used for duration forecasting.

Forecasting in ES is analogous to that of EVM. Due to the unreliability of SPI, EVM has generally not been used for time forecasting (Vanhoucke 2009, p. xiii). Fortunately, Earned Schedule is able to provide reliable time and cost forecasts based on EVM/ES metrics. These Estimate at Completion forecasts are referred to as EAC(t) and EAC(€) for time and cost, respectively. The general formula for time is as follows (Vanhoucke 2014, p. 58):

$$EAC(t) = AT + PDWR, \tag{19}$$

where PDWR stands for Planned Duration of Work Remaining, that is, the estimate for the remaining duration of the project. EAC(t) is thus the estimate for the total project duration RD. PDWR and EAC(t) shall be calculated at each review period. (Vanhoucke 2014, p. 58) Despite the slight difference in terminology presented by PMI, the cost forecast is analogous to the traditional EVM forecast (PMI 2008, p. 185-186; Vanhoucke 2014, p. 59). Hence, the general formula for cost forecast is (Vanhoucke 2014, p. 59):

$$EAC(€) = AC + PCWR \tag{20}$$

where PCWR stands for Planned Cost of Work Remaining, that is, the estimate for the remaining cost of the project. EAC(€) is, thus, the estimate for the total project cost RC.

Similar to EVM, the estimates to completion (PDWR and PCWR) are determined by the performance measures, here referred to as performance factors (PF). Based on the performance factors used, three fundamentally different situations exist (Vanhoucke 2014, p. 59-60):

- PDWR/PCWR according to plan – that is, past performance is not good predictor of future performance. It is assumed that past problems or opportunities do not affect the remaining work, and the work is expected to be performed as per baseline schedule. The performance factor (PF) is thus equal to 1.

- PDWR/PCWR according to current time or cost performance – past performance is well predictive of future performance. It is assumed that the past problems and opportunities affect proportionally to the future performance. The performance factor is equal to SPI(t) or CPI for time and cost, respectively.
- PDWR/PCWR according to current time and cost performance – past cost and schedule problems are well predictive of future performance. In this case the cost and schedule management are considered as inseparable, and the combined effect of the past time and cost occurrences is considered a good predictor of the future performance. Hence, the performance index is equal to ES based Schedule Cost Index (SCI(t)) defined as:

$$SCI(t) = SPI(t) \times CPI. \tag{21}$$

For all of the three situations, the general formulas for time and cost forecasts are the same – the performance factor itself makes the difference (Vanhoucke 2014, p. 63). For cost forecasting, the generic cost forecast formula is the same as for EVM (Vanhoucke 2014, p. 63):

$$EAC(€) = AC + \frac{BAC - EV}{PF}. \tag{22}$$

In order to have the forecasts, the performance factors are further placed in the generic formula. Eight of the more common formulas for cost forecasting in are presented below (Vanhoucke, p. 64):

On budgeted rate, PF = 1

$$EAC(€)_1 = AC + BAC - EV, \tag{23}$$

present CPI

$$EAC(€)_2 = \frac{BAC}{CPI}, \tag{24}$$

present SPI

$$EAC(€)_3 = \frac{BAC}{SPI}, \tag{25}$$

present SPI(t)

$$EAC(€)_4 = \frac{BAC}{SPI(t)}, \tag{26}$$

SPI and CPI, i.e. SCI

$$EAC(€)_5 = AC + \frac{BAC - EV}{CPI \times SPI}, \tag{27}$$

SPI(t) and CPI, i.e. SCI(t)

$$EAC(€)_6 = AC + \frac{BAC - EV}{CPI \times SPI(t)}, \tag{28}$$

SPI and CPI weighed

$$EAC(€)_7 = AC + \frac{BAC - EV}{0{,}8 \times CPI + 0{,}2 \times SPI}, \tag{29}$$

and SPI(t) and CPI weighed

$$EAC(€)_8 = AC + \frac{BAC - EV}{0{,}8 \times CPI + 0{,}2 \times SPI(t)}. \tag{30}$$

For time forecasting, the generic earned schedule duration forecasting formula is analogous to that of cost, and is given by (Vanhoucke 2014, p. 62):

$$EAC(t) = AC + \frac{PD - ES}{PF}. \tag{31}$$

Three of the more common formulas for time forecasting in ES based on different situations are presented below (Vanhoucke 2014e, p. 63):

On budgeted rate, PF = 1

$$EAC(t)_1 = AT + (PD - ES), \tag{32}$$

present SPI(t)

$$EAC(t)_2 = AT + \frac{PD - ES}{SPI(t)}, \tag{33}$$

and SPI(t) and CPI

$$EAC(t)_3 = AT + \frac{PD - ES}{CPI \times SPI(t)} = AT + \frac{PD - ES}{SCI(t)}. \tag{34}$$

In conclusion, the Earned Schedule technique originally developed by Lipke (2003) presents as a worthy alternative to the EVM time metrics. As an extension of the EV metric, ES can be calculated with help of the current value for the EV metric and the known PV line, and thus, extra input is not necessary. The Earned Schedule (ES) metric is thus a translation of EV expressed in monetary units into a metric expressed in time units. ES is found by projecting the EV at current time AT onto the PV curve, where ES values lower than AT indicates delay and ES values greater than AT denote the project being ahead of the baseline schedule.

Similar to the EVM system, the ES metric is used as input for measuring and assessing the time performance resulting in two time-based alternative performance measures SV(t) and SPI(t) which are analogous to the original counterparts. Contrary to the original performance measures, the SV(t) expresses the time variance in units of time and SPI(t) as a percentage of the expected baseline performance. Further, it has been shown that SPI(t) overcomes the quirky behavior of SPI towards the end of the project. Hence, ES metrics are more reliable and also outperform the original EVM metrics in duration forecasting.

2.3.2 Forecasting Quality

A multitude of forecasting methods has been presented in the previous sections. Given the choice, how does a project manager know which method provides the most reliable result for forecasting and decision making? Well, none of the techniques suit for all situations. However, a good indicator of appropriate forecast method is forecast quality which is governed by the project characteristics (e.g. project network logic, project size and costs). To have fitting forecast for each situation, it would be beneficial to continuously validate the forecast quality. (Vanhoucke 2014, p. 66)

The forecast quality can be evaluated with three criteria proposed by Covach et al. (1981): accuracy, timeliness and stability. Accuracy denotes the deviation between the forecast and real observed value (i.e. forecast error) and stability the variation of forecasts (Vanhoucke 2014, p. 66, 68). Timeliness measures the ability to provide reliable forecast as early as possible. Two of the three quality criteria, accuracy and stability, are easily measurable in the course of the project. (Vanhoucke 2014, p. 66)

Accuracy is calculated as the average deviation between the periodic EAC(t) and real duration (RD), and EAC(€) and real cost (RC). The calculation can be based on absolute (MAPE) or relative errors (MPE). (Vanhoucke 2014, p. 66) The Mean Absolute Percentage Error (MAPE) is the average absolute percent error for each time period. Hence, lower MAPE values indicate more accurate predictions. The Mean Percentage Error (MPE), on the other hand, provides average of errors based on total errors, in spite of the sign. Hence, MPE values over zero denote overestimation and lower than zero refer to underestimation. MPE thus sums up the positive and negative errors and they can cancel each other out. Therefore, MPE tends to provide unrealistically low values. (Vanhoucke 2014, p. 67)

The major drawback of accuracy values is they are known only upon the project completion. Fortunately, with help of Monte Carlo simulation and predefined activity duration and cost distributions, the MAPE and MPE metrics for different forecasts can be calculated *ex ante*, and the knowledge is then available prior to the project start. (Vanhoucke 2014, p. 68) Monte Carlo simulation is used to simulate the project progress by generating activity duration and cost projections that deviate from the baseline values and further to assess the impact of these variations to project time and cost objectives (Vanhoucke 2014, p. v).

Stability of forecast values is usually as important as the accuracy (Vanhoucke 2014, p. 68). Stability measures the variability of the predictions over different review periods (Vanhoucke 2014, p. 71). When forecasted value for any review period equals the preceding period's forecasted value, the forecast is considered perfectly stable (Vanhoucke 2014, p. 68). Vanhoucke (2014, p. 68) further suggest utilization of standard deviation of the project overall review periods to measure forecast stability. The upside of stability metrics compared to those of accuracy is that knowledge of the project outcome is not needed, and they can thus be calculated and updated along the project progress. (Vanhoucke 2014, p. 70)

When the reliability of the various forecasting methods can be estimated based on forecast accuracy and stability estimates, one can select the right forecasting method with greater confidence which further allows the implementation of corrective actions based on forecasts with greater probability (Vanhoucke 2014, p. 70-71). However, one should not be blind to the accuracy and stability only. Every project is unique and potential future occurrences can be foreseen with certain confidence that are not reflected in the schedule. Hence, it is imperative to share the knowledge behind the forecasts (e.g. boundaries, limitations and degree of confidence) for the authorized decision-maker (i.e. project manager) for him or her to be able to make the right decisions. (Kim, Kim 2014)

2.3.3 Schedule Adherence and p-Factor

In dynamic scheduling, it is implicitly assumed that the significance and use of a project baseline schedule is rather limited (Vanhoucke 2014, p. 41). The baseline schedule should not be considered more than a point of reference, a predictive model of enabling resource efficiency calculations, time and cost risk analyses, project control and performance measurement (Vanhoucke 2014, p. 41-42). It is, nonetheless, material for project control using EVM or ES. The timing and logic of the baseline schedule is merely a benchmarked reference point that acts as reference point for corrective actions, not the goal itself. In static scheduling the baseline schedule is considered as a fact and deviations are seen as unexpected changes. However, in dynamic scheduling, deviations to the baseline schedule are seen as inevitable and signals for corrective actions. (Vanhoucke 2014, p. 42)

The concept of schedule adherence is to integrate the static and dynamic scheduling philosophies by establishing the connection between the static project baseline schedule and dynamic progress. It is assumed that both the logic and timing of the baseline schedule should be respected, and network logic deviations are potential risk factors despite the progress. Hence, the added value of the concept resides in the emphasis on the network logic and the baseline schedule. (Vanhoucke 2014, p. 42) Lipke (2004) has introduced the new p-factor concept as an extension to EVM and ES methodologies. However, consideration shall be taken since this newly introduced idea has not yet passed the test of logic (Vanhoucke 2014, p. 42).

The p-factor is a measure to provide the connection between project output and EVM/ES. The concept assumes that working against the baseline schedule logic oftentimes indicates activity impediments or may cause rework. Consequently, it is premised that impediments, i.e. activities of inefficient performance, cause shift of resources from constrained activities to those of potential to gain earned value which, without the necessary input, are at risk of certain portion of rework. (Vanhoucke 2014, p. 43) Indeed, the use of traditional EVM has been stated questionable, potentially leading to incorrect management decision, when a project is subject to vast amount of rework (Chen, Zhang 2012)

To introduce the p-factor concept, a more detailed definition of PV and EV is necessary. Now subscript *i* refers to the activity level (instead of the project level) and *t* to the point of time. Consequently, $PV_{i,t}$ and $EV_{i,t}$ denote the planned and earned value of activity *i* at time *t*, respectively. (Vanhoucke 2014, p. 43) Further to present the mathematical formula of p-factor, the following explanations are necessary (Vanhoucke 2014, p. 43):

N	Set of activities in the project → known from the project network
$EV_{i,AT}$	Earned value of activity *i* at the actual time AT → calculated at each review period = fraction of the activity PV earned at AT for the work done

$PV_{i;ES}$	Planned value of activity i at time instance ES → PV is known from the baseline schedule → ES calculated at each review period
p	p-factor → calculated at each review period based on the current PV and EV = fraction of the total EV accrued before ES = 1: perfect schedule adherence < 1: lack of schedule adherence.

The p-factor measures the portion of earned value accumulated as per the baseline schedule (Vanhoucke 2014, p. 44):

$$p = \frac{\sum_{i \in N} \min(PV_{i,ES}, EV_{i,AT})}{\sum_{i \in N} PV_{i,ES}}. \quad (35)$$

Hence, the p-factor is the ratio of the EV in congruence with the baseline schedule divided by the total PV at time instance ES. Hence, p-factor expresses the degree of earned value accrued as per the baseline schedule between 1 and 0 (or 100% and 0% respectively), 1 corresponding to 100% schedule adherence. (Vanhoucke 2014, p. 44)

The import of the p-factor can be illustrated graphically on a Gantt chart incorporating the planned activity durations with the activity progress (Vanhoucke 2014, p. 46). In Figure 10 below, the bars denote the start and end dates of activities as per the baseline schedule, and black portions represent the percentage of completion as per EV at the current time AT = 4 when ES is equal to 3.19 weeks (Vanhoucke 2014, pp. 46-47). The portion of the work for each activity (1, 2 & 3) performed before the ES line is in line with the baseline schedule; the portion of the work performed after the ES line (see activities 7 & 8) is presumably performed under a certain degree of risk. The p-factor is then sum of the portion of the black bars before ES line divided by total EV, i.e. sum of all black bars. In reference to the baseline schedule, the ES line delineated as the point in time where PV is equal to EV. Hence, the ES value is the time at which as the EV should have been accrued as per baseline schedule. Mathematically speaking, the value of PV at time instance ES is the sum of planned values up until ES for activities starting before ES, that is, the denominator of the formula (35). The numerator is then the EV corresponding to the portion of these activities not exceeding the planned values at ES. (Vanhoucke 2014, p. 47)

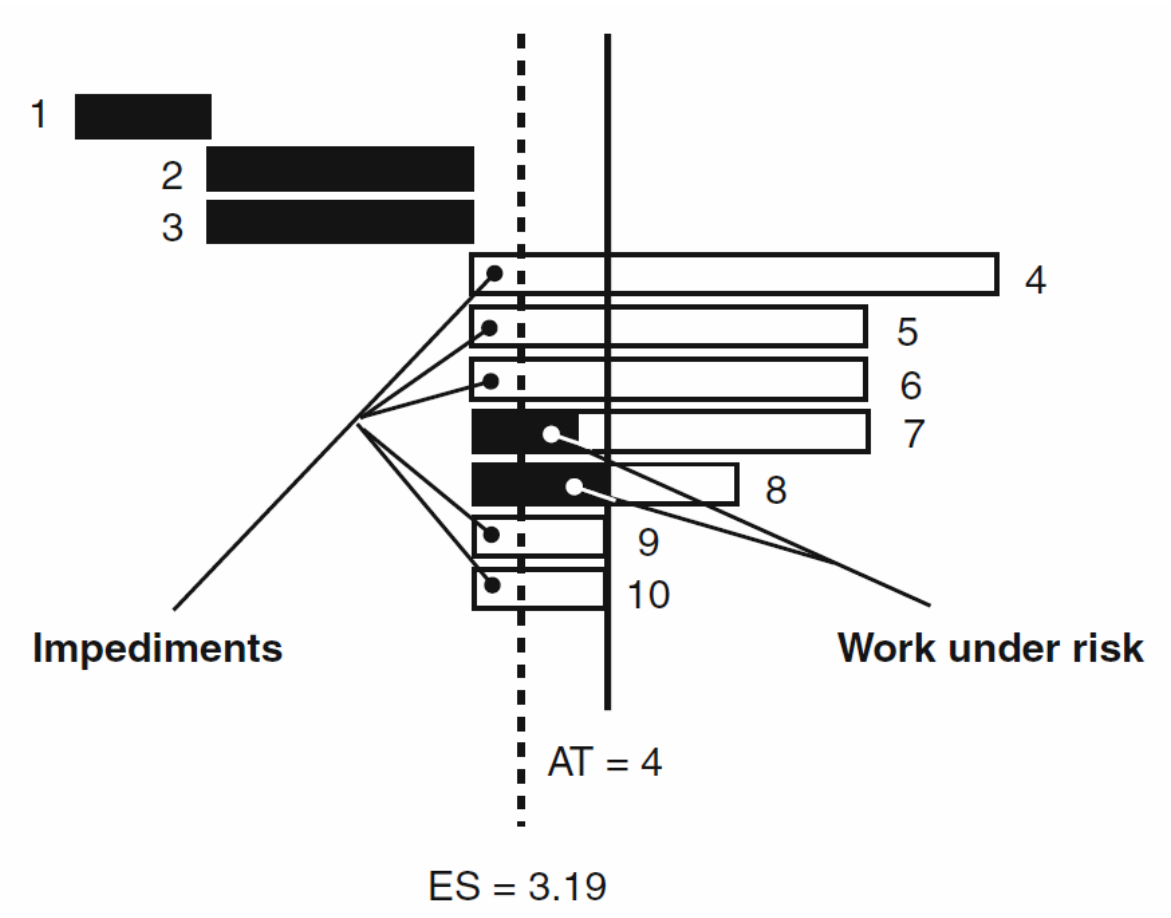


Figure 10. p-factor Gantt chart representation: connecting project progress to the baseline schedule (Vanhoucke 2014, p. 46)

Now the contribution of p-factor lies in revealing the impediments or constraints in order to detect the portion of the work executed under risk which may lead in inefficient resource usage lagging the ES performance. This inefficiency is expressed by the p-factor. By means of p-factor, the accrued earned value can be corrected with the risk of rework. The effective earned value EV(e) is this risk-adapted portion of the earned value performed as per expected baseline schedule performance, defined by the earned schedule metric. (Vanhoucke 2014, p. 47)

The causes for lack of schedule adherence, indicated by p-factor, can be separated into two disjoint subsets by splitting the accrued earned value with the ES metric as follows (Vanhoucke 2014, p. 47-48):

- Portion left of the ES line – assumed to be performed without risk but might reveal presence of impediments or constraints (see activities 4, 5, 6, 9 & 10 in Figure 10).
- Portion right of the ES line – work ahead of normal project performance but is assumed to involve certain degree of risk (see activities 7 & 8 in Figure 10).

As described earlier, the p-factor assumes that the degree of risk is often proportional to inefficient use of resources against the baseline schedule logic. For example, Figure 10 could reflect a situation where resources were shifted from the constrained activities (4, 5, 6, 9 and 10) to those of potential to gain earned value (7 and 8) but with the risk of potential rework. However, a correction to the earned value can be made to segregate the distinctive portions of work performed without and under plausible risk. Indeed, p-factor is the measure that expresses the portion of the EV without risk. This is referred to as the effective earned value EV(e), and the portion of potential risk denoted as EV(r). (Vanhoucke 2014, p. 48) In relation to EV(e) Vanhoucke (2014, p. 48) further elaborates that by definition:

"The risk-adapted portion of earned value that is performed within the expected baseline schedule performance, taking into account that only R% ∈ [0%, 100%] of the EV(r) will be accounted risk-free".

The necessary metrics are displayed in order to explain the mathematical formula as follows (Vanhoucke 2014, p. 48):

EV	Total earned value
EV(p)	Risk-free earned value = p*EV
EV(r)	Remaining earned value portion performed under risk = (1 - p) * EV
EV(e)	Effective earned value = EV(p) + R% * EV(r)
R%	Estimated portion of EV(r) that is usable and requires no rework → User defined estimate.

Due to the likely cause of rework for the portion of earned value under risk, the effective earned value EV(e) is lesser than the total earned value (Vanhoucke 2014, p. 49). Hence (Vanhoucke 2014, p. 49):

$$EV = p \times EV + (1 - p) \times EV = EV(p) + EV(r), \tag{36}$$

and

$$EV(e) = EV(p) + R\% \times EV(r). \tag{37}$$

Thus the valuation of work performed under risk equals to the value of the work not performed in line with the planned value at time ES shown by the inefficient activities. The fraction of work performed under risk of (100% - R%) is therefore considered as value lost owing to the lack of schedule adherence (resulting from the expected rework). (Vanhoucke 2014, p. 49)

Potential reasons leading to lack of schedule adherence (p-factor < 1) can be divided into four categories (Vanhoucke 2014, pp. 49-50):

- Deviations in baseline estimates – progress deviating from baseline activity and cost estimates leads to deviation in expected time and cost performances, and potentially shifts in resources.
- Early or late start times – may lead to unexpected project performances and shifts in resources.
- Overlaps between activities – the schedule logic of the precedence violations and consequential overlapping of activities embodies execution of activities with insufficient input and hold certain degree of risk due to potential rework.
- Deviations in EV accrues – the EV accrue and PV accrue assumption might be different. Various PV accrue assumptions can be chosen from various earned value measurement methods (e.g. fixed formulas or % complete estimates). Differences in EV accrue and selected PV accrue system will be reflected in the p-factor.

The aforementioned reasons may as well lead SPI(t) to differ from 1 indicating deviation from the expected performance. Nevertheless, p-factor shall not be considered as a replacement for SPI(t). For example, SPI(t) may indicate close to perfect performance whilst p-factor values are significantly lower than 1. However, it is assumed that p-factor provides much more value than SPI(t) since it elicits certain dimensions of project performance that are not considered by SPI(t). Further p-factor does not measure performance but takes it as given. It only detects inefficiencies in project progress relative to the baseline logic. It is noted that more research is needed to clarify the difference between project performance and schedule adherence. (Vanhoucke 2014, p. 50)

2.3.4 Earned Value Management - State of the Art

It is well known that earned value has originally evolved from a cost management technique that is now been applied as Earned Value Management technique gaining high degree of acceptance (Anbari 2003; Wood 2017). It is now also acknowledged as a best practice technique by PMI (2005, p. 40). Owing to its origin, the early research has had a great emphasis on cost objectives of the project while relatively less attention has been given for the time and scope dimensions (Vanhoucke 2014, p. 134; Wood 2017). More recently the research focus has shifted from costs towards time objective which will be evident from the following.

Back in 2004, Jacob and Kane (2004) had observed that most of the schedule prediction methods yielding similar accuracies may be due to the same basic parameters. Further it was well known from the time of the development of EVM indicators that the schedule indicators are flawed (Lipke 2003; Lipke et al. 2009; Wood 2017). Later the formal description of time indicators presented by Lipke (2003) resulted in proposition of the Earned Schedule methodology which has become accepted as the most reliable EVM metric for deriving to-completion forecasts (Lipke et al. 2009; Wood 2017). What is more, a study of Henderson and Lipke (2006) suggests that ES yields more consistently reliable schedule forecasts than Critical Path method. Not only does ES provide fairly reliable duration and completion forecasts, but in fact, Lipke et al. (2009) results indicate an overall better prediction for schedule than for cost. Now considerable evidence of its application exists indicating its general acceptance, despite the lesser reliability as to-completion indicator for projects with multiple parallel work paths (Henderson 2004; Vanhoucke 2006, 2007; Lipke 2013, 2014). Lipke (2004) further developed the effective earned value metric which incorporates the measurement of schedule adherence with the earned value concept. Indeed, the development of more accurate EVM metrics for project monitoring and forecasting has been a fertile area of research in the past 15 years (Wood 2017).

Although the ES technique has been considered the best alternative to simplify the management of project schedule, the use of cost data as time value proxies makes it subject of possible improvements (Vanhoucke et al. 2015).

Quite recently, Khamooshi and Golafshani (2014) have proposed a new approach, Earned Duration Management (EDM). Despite the almost similar name, it is imperative to understand that it is different from the well-known Earned Duration method proposed by Jacob (2003). EDM, as exclusively time-based methodology, is thus deemed to overcome some of the shortcomings of the generally accepted earned value and earned schedule methodologies which use cost data to control duration. Most of the data needed for EDM is promptly available from EVM data and the calculations are very similar to known ES counterparts. (Khamooshi, Golafshani 2014; Vanhoucke et al. 2015)

In spite of its novelty, EDM has gained considerable positive attention amongst the researchers. It has been shown that the earned duration (ED) performance measure, Duration Performance Index (DPI), seems to respond quickly to changes in activity execution and yields slightly more reliable to-completion duration forecasts than those of ESM (Batselier, Vanhoucke 2015; Vanhoucke et al. 2015). Especially if able to surpass the forecasting accuracy of ESM forecast based on planned performance, which implicitly considers the potential corrective actions, the unweighted EDM(t)-based method might yield a new overall best performing method (Batselier, Vanhoucke 2015). Later Khamooshi and Abdi (2016) have also suggested that Earned Duration Index (EDI) should be preferred over SPI(t), especially if complemented by exponential smoothing techniques. Indeed, EDM could be seen as a novel base methodology for forecasting project duration (Batselier, Vanhoucke 2015).

Although EDM is bound to replicate the success in project cost management, it is perceived as rather difficult to assimilate amongst professionals. Yet there is definite need to demonstrate the power of EDM and validate its seemingly promising potential. (Vanhoucke et al. 2015) For all its potential, the approach does not provide much novelty in regards of cost management and forecasting, and hence, is not further addressed herein (Khamooshi, Golafshani 2014; Wood 2017).

Another deterministic extension was introduced by Elshaer (2013). He integrated activity sensitivity information in ESM time forecasting in an attempt to remove the false warning effects caused by the non-critical activities. Out of four sensitivity measures the Criticality Index (CI) proved the most reliable metric in forecasting a project's final duration. (Elshaer 2013)

2.3.5 Risk and Uncertainty

Construction contractors are generally subject to global risk factors. Notwithstanding, they tend to lack effective techniques to handle such risks. Traditionally risk management has rested upon experience and subjective judgement. On the contrary to mechanistic systems, humanistic systems, heavily dependent on human judgement and perceptions, are not characterized by similar precision. Hence, there has been growing interest to explore and develop management methods capable of incorporating and assessing certain degree of risk. (Baloi, Price 2003)

The approach of EVM is deterministic by nature. Hence, EVM does not consider the underlying uncertainty and risk in relation to cost and time in the project environment. (Wood 2017) Recently researchers have attempted to tackle this issue with stochastic and fuzzy approaches (Batselier, Vanhoucke 2015; Willems, Vanhoucke 2015; Wood 2017). Stochastic techniques incorporate higher degree of variability (or randomness) resulting in distributions and confidence intervals around the estimates (Willems, Vanhoucke 2015). The fuzzy techniques, on the other hand, consider the uncertainty (of events and systems) arising from vagueness and fuzziness rather than randomness alone. Hence, the resulting indicators or estimates are not always expressed as fixed numbers but instead described in linguistic terms. (Moslemi Naeni, Salehipour 2011; Willems, Vanhoucke 2015) These terms are then translated into fuzzy numbers and finally defuzzificated to enable evaluation and comparison of these fuzzy numbers (Willems, Vanhoucke 2015). The most important findings in relation to these uncertainty accounting techniques will be addressed in the following.

Stochastic Techniques

Now, stochastic models have been applied to EVM and they aim to address the uncertainties by applying various methodologies (Wood 2017). The mathematics of statistics were introduced into ES by Lipke et al. (2009) to establish confidence limits for final cost and duration predictions. The concept of stochastic S-curves (i.e. SS curves) was introduced by Barraza et al. (2000, 2004) first for monitoring project performance and further to determine forecasted project estimates and evaluate the performance improvement of proposed corrective actions. The studies were complemented by Barraza and Bueno (2007) introducing a technique allowing probabilistic assurance of acceptable final project performance. Nassar et al. (2005) have also approached the stochastic evaluation of schedule performance of construction projects with a technique integrating EVM and Weibull analysis. Similarly, Kalman filter has been incorporated into ES method by Kim and Reinschmidt (2010) in an attempt to provide probabilistic predictions of project duration at completion. Only one year later, from the same authors, a Bayesian adaptive forecasting method, referred to as cost-BAF, was presented for better cost forecasting which incorporates the actual performance EVM data and revises preproject cost estimate (Kim, Reinschmidt 2011). The Bayesian methodology was also exploited by Caron et al. (2013) who described and tested a Bayesian model within the EVM framework aiming to provide better cost and schedule estimates at completion of the project. Later inspired by the well-known statistical process control charts, Colin and Vanhoucke (2015) suggested setting statistical limits to control EV in order to better address uncertainty.

New probability based EVM metrics have also been developed quite recently. Pajares and López-Paredes (2011) developed two new EVM metrics, Cost Control Index (CCoI) and Schedule Control Index (SCoI) to address the uncertainty of project parameters. To support in determining whether corrective actions are necessary, the objective of the metrics is to indicate whether project overruns are within the expected variability or due to structural deviations. Acebes et al. (2013) have represented the evolution of the aforementioned control indices and proposed two additional measures to enable graphical determination of delay and overrun of expected variability with support of Monte Carlo simulation.

Fuzzy Theory

Fuzzy numbers and sets have also been applied to EVM metrics to better address certain project uncertainties. In 2003, Baloi and Price (2003) averred that “global risk factors affecting construction cost performance can be successfully modelled, assessed and managed using Fuzzy Set Theory and Decision Support System [DSS] technologies”. Not much later, Noori et al. (2008) introduced the concept of fuzzy control charts associated with α-cut in order to control SPI/CPI trend in earned value method. Mortaji et al. (2013) developed an EVM incorporating L-R type fuzzy numbers which they claim to improve applicability of EVM under uncertainty, overcome drawbacks associated with typical fuzzy sets and numbers, and lead to better MR planning and effective decision making. Additionally, an efficient approach to estimate the final cost of the project (EAC) was presented. An approach to deal with newly developed fuzzy earned value indices evaluating them also using the α-cut method was introduced by Moslemi Naeni and Salehipour (2011). Later a new fuzzy-based earned value model was presented by Moslemi Naeni et al. (2014) which is deemed overcome the challenge of developing and analyzing the earned value indices and the time and cost estimates at completion in uncertain conditions. Salari et al. (2014) have also taken advantage of the fuzzy theory and proposed a model to extend the EVM utilizing fuzzy sets to better estimate financial performance of the project under uncertainty. The proposed two new metrics, Financial Performance Index (FPI) and Project Performance Index (PPI), are suggested to better address the effect of cash inflow money on the project performance and consider the influence of delay in client payment on project progress, respectively. Fuzzy regression was also used by Salari et al. (2015) in an attempt to integrate the well-known time-cost trade-off and the project performance during project execution phase.

2.3.6 Progress Linearity

Another aspect of critique for EVM has been its fundamental assumption of progress linearity (Jacob, Kane 2004; Vandevoorde, Vanhoucke 2006; Stimpson 2007). Consequently, the analytic expression for the shape was being developed and examined by Cioffi (2005). Vanhoucke and Vandevoorde (2008) and Vanhoucke (2009) later concluded that network parallelism (i.e. lower degree of criticality of project activities) increases the variability, also provoking the S-curve shape (Cioffi 2005), and thus degrades forecasting accuracy. Approaching from the practical point of view, Stimpson (2007) further challenges the expediency of progress linearity. For example in industrial construction the project lifecycle consists of rather dissimilar phases which could be performed by unrelated teams, or even subcontracted. Therefore it might not be appropriate to assume that all disciplines of work would progress as steadily or encounter similar problems. (Stimpson 2007) Given the widespread critique, there has been strong motive to develop nonlinear theories (Warburton, Cioffi 2016). The following will address the most important findings in relation to the linearity issue and nonlinear approaches to EVM.

Back in 2006, Evensmo and Karlsen (2006) tackled the linearity assumption behind the well-known ES approach and proposed a cubic polynomial cost curve. A logistic model that interpolates the nonlinear S-curve was proposed by De Marco et al. (2009) enabling the evaluation EAC(t) by considering the specific initial behavior of a project schedule. Later Narbaev and De Marco (2013, 2014) proposed a Gompertz-based growth model integrated with ES technique, using nonlinear regression curve fitting aiming for better EAC(€) cost forecasts. The study suggests that such inclusion of the schedule progress as a factor in the cost performance increases the forecast accuracy (Narbaev, De Marco 2013). In the meanwhile, a time-dependent EVM model was developed by Warburton (2011) for projects following the nonlinear Putnam-Norden-Rayleigh (PNR) labor curve profile. Later Warburton (2014) continued his research and instead used a trapezoidal labor profile by Allen (1979), often used to describe construction projects, to attain precise early project estimates. Chen et al. (2016) have also succeeded in improving the forecasting accuracy by enhancing the predictive power of PV. A step-by-step methodology was presented including logarithm linear transformation of the PV data and linear regression modeling (Chen et al. 2016). Most recently, Warburton and Cioffi (2016) have established "a sound theoretical basis for project duration estimation using the standard definitions of EVM, which resulted in a duration triad (planned, earned, and actual duration) analogous to the EVM cost triad". Owing to its generality, they deem the theory to apply to both linear and nonlinear cost curves (Warburton, Cioffi 2016).

2.3.7 Consideration of Other Performance Factors

Another fundamental factor that earned value methodology has been criticized over the years is the two-dimensional approach (Paquin at al. 2000; Rozenes et al. 2004). Project management encompasses dimension that go beyond time and cost in order to achieve project objectives, and hence, the approach is lacking the broader picture. Therefore, the integration of additional control dimensions such as quality, design, technology and sustainability would be beneficial to attain more comprehensive approach in project management. Especially quality has been stated to be "important factor for the successful implementation of a project", "defined as being equivalent to proper performance of the project content" and moreover the "most important project objective". (Rozenes et al. 2004) Indeed, many authors in the recent history have attempted to establish a more comprehensive approach to overcome these shortcomings of EVM (Rozenes et al. 2004; Lauras et al. 2010; Hazir 2015). However, considering the context of this study, the focus of the following will be in area of research aiming to extend the EVM methodology by integration of additional dimensions rather those disregarding EVM.

Quality is an integral part of the project management triangle (Atkinson 1999). Therefore, it is quite natural that the integration of quality as an additional dimension to EVM has been of debate (Paquin et al. 2000). In an attempt to integrate quality into EVM, Paquin et al. (2000) proposed an Earned Quality Management (EQM) method integrating the quality to EVM by means of quality breakdown structure (QBS), hence being another tool rather than an extension to EVM. Not much later Rozenes et al. (2004) introduced a Multi-dimensional Project Control System (MPCS), and used Data Envelope Analysis (DEA) (Vitner et al. 2006) to integrate it into Earned Value Management System (EVMS). Solomon and Young (2007) have also proposed Performance-based Earned Value (PBEV), a more comprehensive methodology, incorporating product quality requirements into traditional EVM, which they argue to be an enhancement to EVMS.

An approach considering sustainability in addition to time and cost was introduced by Kim et al. (2014) referred to as Integrated CO2, Cost and Schedule Management (ICCSM). They developed a set of formulas with weighed parameters where CO2 had been weighed in with time and cost. Authors further asserted that the developed ICCSM system provides benefits to the environment in terms of construction management (Kim et al. 2014). Most recently Dodson et al. (2015) contributed this area of research introducing a methodology referred to as Quality Earned Value (QEV) adding the quality component into EVM. In this approach the quality baseline is set and quality performance is evaluated in parallel with time and cost. Although further validation and development is recommended, the authors concluded that the results indicate potential in adding the quality as a component in EVM. (Dodson et al. 2015) In conclusion, the aspect of integrating other factors to earned value methodology is expected to be fertile ground for future research (Rozenes 2004).

2.3.8 Other Approaches

Kerkhove and Vanhoucke (2017) introduced an adapted EVM approach, the Earned Incentive Management (EIM), which they claim to "significantly [outperform] conventional EVM/ES methods, and should therefore be preferred in projects where cost and time incentives play a significant role".

Lastly, Czemplik (2014) has suggested a Schedule Forecast Indicator (SFI), a "simpl[e] and effective" supplementary managerial tool, to support effective decision making in processing variation orders with respect to conservative schedule requirements. The SFI aims to express the probability of successful cancellation of the delay at various phases of the project (Czemplik 2014).

2.3.9 Future Work

Vast amount of research in relation to EVM has been carried out during the last decades. Despite numerous efforts, a wide gap still exists between academic research and practice needs. Reasons are multifold but four broader trends can be identified. First, the main focus of research has been put on the cost objective of projects relatively scanting the time and scope dimensions. Second, the static solution processes have drawn relatively more attention and dynamic oriented approach is freshly growing. (Vanhoucke 2014, p. 134) Third, the interlinked phases of project management process are not well integrated. And fourth, only little effort has been given to reveal the actual drivers of project success (Vanhoucke 2014, p. 135).

Stability of EVM/ES forecasting methods, especially in relation to costs, has been a central point in EVM research. The research on integration between accuracy and stability, and their potential trade-off, however, seems to be completely void. (Vanhoucke 2014, p. 133) Similarly the promising p-factor concept developed by Lipke (2004) has been overlooked although Lipke's (2003) ES concept has gained widespread attention. Vanhoucke (2014, p. 134) believes that research on p-factor and similar approaches would help to fill the void in the integrative accuracy/stability research need. Moreover, there is also room for further research of probabilistic forecasting, and EVM and Schedule Risk Analysis (SRA) integration in order to improve the ability to predict the final project outcome. (Vanhoucke 2014, p. 133)

It is notable that there has been an increased attention towards the stochastic nature of projects. However, enhanced validation of the proposed methodologies (with large historical datasets or simulation experiments) is imperative in order to gain widespread acceptance. There is also room for expansion of integrated control models considering other factors along with cost and time. Lastly, and quite interestingly, the development, implementation and analysis of corrective action procedures has not yet received much attention. (Willems, Vanhoucke 2015) Development of a more comprehensive approach, "a statistical project control method that incorporates the static and dynamic information in order to better support corrective actions in case the project objectives are in danger" is also of great interest (Vanhoucke 2014, p. 136).

2.4 Best Practices - Dos and Don'ts of Earned Value Management

2.4.1 What It Is and What It Isn't

First and foremost, one must understand that use of EVM is not a guarantee of good results. C/SCSC, the antecedent of EVM, was never expected to eliminate cost overruns or schedule slippages. Rather, C/SCSC was a tool to assist in determining the project status, total duration and costs for better decision making. (Fleming 1992) And the same applies for EVM. It should be used according to its purpose. (Czarnigowska et al. 2011)

It is equally important to know what EVM is, and what it isn't. EVM is a tool to facilitate progress monitoring, determination of project status and scale of current variances which may act as early warnings of project problems in order to initiate corrective actions (Fleming, Koppelman 2006; Czarnigowska 2008). Although it is able to provide a rough estimate of the combined effect on the project's outcome, EVM in itself is not a tool for forecasting. As a linear extrapolation of current tendencies, it does not allow for any future risks or effects of potential corrective actions. More accurate forecasting methods should be applied if the project is to be managed consciously. (Czarnigowska 2008)

2.4.2 Managing the Scope

In the planning phase, the first step is to define the scope. Without appropriate definition of scope, proper scheduling and budgeting is not possible. For defining the scope of work PMI (2005, p. 2) suggests a Work Breakdown Structure (WBS) that is considered an integral part of project management and one of the most useful tools for any project manager (Fleming, Koppelman 2006; 2007). WBS is a hierarchical decomposition of project work necessary to accomplish the project objectives and produce deliverables (PMI 2013, p. 125). By definition, the process of decomposing project deliverables into smaller components shall continue until the cost and duration of work can be reliably estimated and managed (PMI 2008, p. 116).

As a deliverable-oriented grouping of project elements WBS establishes the framework for managing the work throughout the project and facilitates in managing, defining and communicating the project scope (PMI 2006, p. 1; Buchtik 2013, p. 1). In context of cost management, WBS is a tool of scope management which works in conjunction with EVM (PMI 2005, p. 20).

Generally the development of work breakdown structure is governed by one rule only – the 100% rule. Haugan (2002, p. 17) defines the rule as follows:

"The next level decomposition of a WBS element (child level) must represent 100 percent of the work applicable to the next higher (parent) element."

In a well-designed WBS the information is presented at the appropriate level of detail and in formats and structures meaningful to those performing the work (PMI 2006, p. 6). The required level of detail for work packages is subject to project size and complexity (PMI 2008, p. 116). Suggestion for appropriate work package size varies from 8 to 80 hours of direct labor (Taylor 2008; Devi, Reddy 2012; Stumpe 2013). However, it is also suggested that duration of a work package should not exceed one reporting period (Grisham 2010; Stumpe 2013). Further, it may also be useful to apply "common sense" in determining the size of a work package (Stumpe 2013). Similarly regarding WBS levels, an absolute correct amount does not exist. However, two levels is considered an absolute minimum, and suggestions vary from three to six levels depending on project dimension and complexity. (Brotherton et. al. 2008; Buchtik 2013, p. 56) Lastly, WBS also includes identification codes identifying the hierarchical nature which are assigned for each and every element (Brotherton et. al. 2008; PMI 2008, p. 116).

In a broader context, the function of WBS is multifold. First, in regards of project planning and monitoring, WBS provides a framework for specifying performance objectives basis for integration and assessment of schedule and cost performance. Second, WBS supports in assigning responsibilities and assists in determining resource requirements. (PMI 2006, p. 7) Each WBS component should have a person assigned to it, a person in charge, to ensure that all pieces of work are being achieved (Buchtik 2013, pp. 12-14). In consequence, reporting and assessment of project progress and status data are being facilitated (PMI 2006, p. 7). Third, WBS provides a baseline for scope change control. That is, the WBS guides the project team through the process of reviewing and approving or rejecting requests to change the project scope. (Buchtik 2013, p. 12)

In relation to project management, WBS contains characteristics that are of utmost importance. In addition to the inherent advantages of using a WBS, constructing a WBS provides the project team with understanding of the work already at early stages of the project, also for areas with limited understanding (Buchtik 2013, pp. 10-11). Considering the integral involvement of WBS in project management processes, it is evident that poorly constructed WBS can result in incomplete project definition and ambiguity in work assignments, goals, objectives or deliverables (PMI 2006, p. 13-14). Naturally WBS alone cannot ensure project success but project failures can often be traced back to a poorly developed or nonexistent WBS (PMI 2006, p. 13). Unsurprisingly, PMI (2006, pp. 31-32) encourages the development and use of WBS templates or standards to assist in developing detailed project specific WBSs.

In project management context, the WBS should reflect all project requirements which are further formulated into tangible, measurable deliverables (Lukas 2008). Therefore, once the WBS is formulated, it is essential to check the WBS against the requirements, but also to see if it includes deliverables that do not relate back to the requirements. This is to ensure that none of the requirements are missed and, moreover, that resources are not wasted on unnecessary deliverables. A useful method to facilitate the check would be to establish a WBS dictionary which includes list of requirements covered by each WBS elements. (Lukas 2008)

The plan has to be integrated and thus developed on the basis of WBS. The scheduled tasks shall reflect back to WBS. That is, the schedule shall include tasks corresponding to each WBS work package, with the exception of ongoing project administrative functions (e.g. administrative support). (Lukas 2008) Further, each work package shall be associated with a statement of work (i.e. what is expected), an authorized budget and only one individual responsible for the performance (Lukas 2008; Gershon 2013).

Prior to finalization of the project plan, the schedule should also be checked for potential errors (Lukas 2008). Lukas (2008) has noted that mistakes such as hangers, improper relationships and misuse of constraints are quite common, as well as miscommunication, quantity errors and use of wrong rates in regards of budgeting and estimates. Even the most experienced people make mistakes. Therefore, a quality control process should take place to minimize the mistakes in the schedule and estimates (Lukas 2008).

To conduct proper EVM, it is imperative to have a change management process in place. All of the changes must be addressed properly and also incorporated into the current plan. Lukas (2008) also asserts that allocation of potential contingencies or contingency reserves, i.e. provisions for known unknowns, should also take place in the change management process. One does not really know when the contingencies are spent, and hence they should not be included in the original planned value curve either. When the risk materializes and change request has been accepted, the contingencies can then be allocated to the work packages in question and the PV curve is modified. (Lukas 2008) The view of Lukas however contradicts with PMI (2008, p. 177) which seems to suggest to include the contingency reserves in the performance measurement baseline but to leave the management reserves out. These contradicting views are illustrated in Figure 11 where the striped section represents the bone of contention – whether to be included or excluded in the performance measurement baseline.

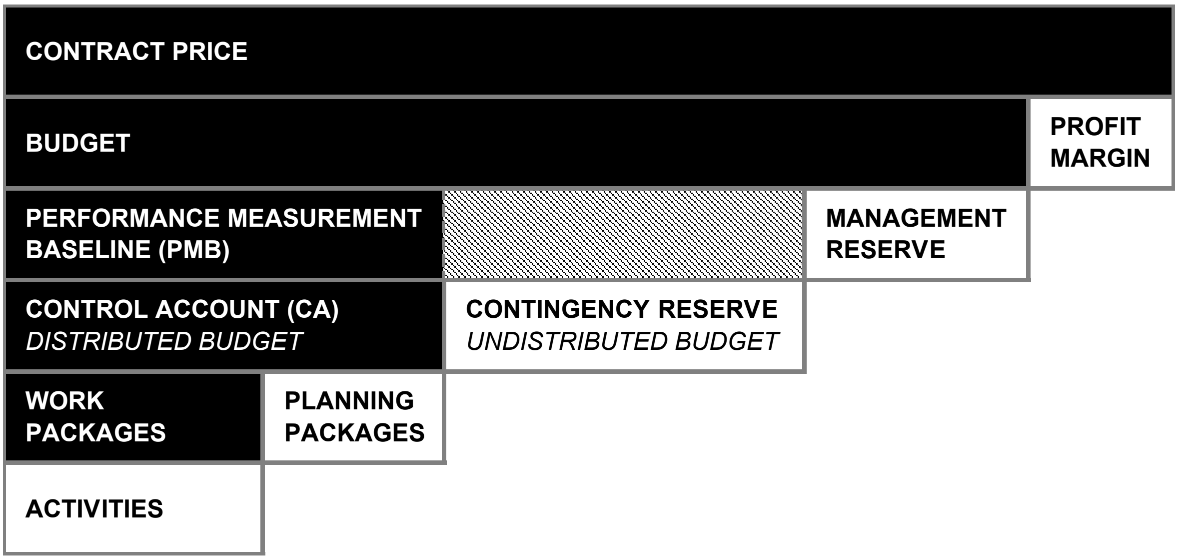


Figure 11. Budget and contract price build-up in EVM terms (Lukas 2008; PMI 2008, p. 177; Mosaic 2012; APM 2013)

2.4.3 Measuring and Reporting Earned Value

In order to allow effective management with earned value, the infrastructure has to be on point. That is, EVM must be supported with satisfactory cost and schedule control systems. Especially cost management and tracking should be of priority. (McConnell 1985; Gershon 2013) In reporting the actual costs, it is essential to understand how costing and the company's cost collection system work. The billing period is often shorter than reporting period and invoices may lag significantly from the work performed. (Fleming, Koppelman 2006; 2007; Lukas 2008) Use of direct output from the cost system can therefore be misleading. Instead, actual direct labor hours can be used for more frequent reporting of internal works (Fleming, Koppelman 2006; 2007). But then, actual hours are rarely available for contracted works (Lukas 2008). Hence, it is advisable to use "adjusted actual cost", the actual recorded cost plus accruals (i.e. expenses that have been incurred but are not yet recorded in the accounts), for reporting actual costs. For the sake of consistency, it is suggested to include a procedure for cost reporting, including the frequency and determination of "adjusted actual costs", in the project plan. (Lukas 2008)

As a quantitative methodology, earned value greatly hinges on how progress is being reported. Use of quantity-based progress measures, such as units completed or incremental milestones, provides more consistent results. Qualitative measurement allows for potential gaming and the team bias to creep into the reported progress. (Fleming, Koppelman 2007; Lukas 2008) However, the quantitative approaches are not equal either (Ruskin 2004).

Three of the most common quantitative methods to determine the earned value are percent complete (% completion), equivalent units and earned standards. The equivalent units technique measures number of units completed in one-to-one fashion in order to determine the earned value presented in monetary terms, fractional equivalents or even multiple hours per unit. In earned standards method the determination of completion percentage is based on a preset-standard of performance which is measured against the tasks being executed. The methods are usually back-up with historical data. The third method is determination of percent complete. (Stimpson 2007)

Indeed, the completion percentage can be determined in various ways. Depending on the task, Fleming and Koppelman (2006; 2007) suggest one of the following discrete measurements: milestones (0-100 percent measurements), fixed formulas (e.g. 25-75, 50-50 or 40-60), percent completion estimates, or percent completion estimates with milestone gates. Percent completion estimates with milestone gates means that the work is divided into segments and the predefined value of each segment is earned when predefined criteria (e.g. specific deliverable) is being satisfied. Similar to the specific milestone measurement, this approach possesses the ease of administration and built-in checks. (Fleming, Koppelman 2006; 2007)

Ruskin (2004) has compared three of these common fundamental quantitative approaches: % completion, fixed formula, i.e. 50-50 and similar, and 0-100 approach. The more common approaches are illustrated in Figure 12. The % completion approach, also referred to as "eyeball estimates", seems good on paper. However, it is subject to inadvertent or even intentional biases and lacks repeatability. Fixed formula approaches (e.g. 25-75, 33-67 or 75-25) produce more reproducible assessments than eyeball estimates. However, they too have two disadvantages; they credit too much earned value when the work has been only started, and the earned value credited for nearly completed elements falls short of reality. 0-100 approach still undervalues partially complete products but avoids overly optimistic assessments. However, the smaller is the amount of assessed elements, the lesser is the undervaluation of the overall project. Hence, 0-100 assessment complemented with a WBS developed to fairly low levels and small elements produces conservative final cost and duration estimates, and also inhibits from labor-intensive monitoring and reporting efforts. (Ruskin 2004)

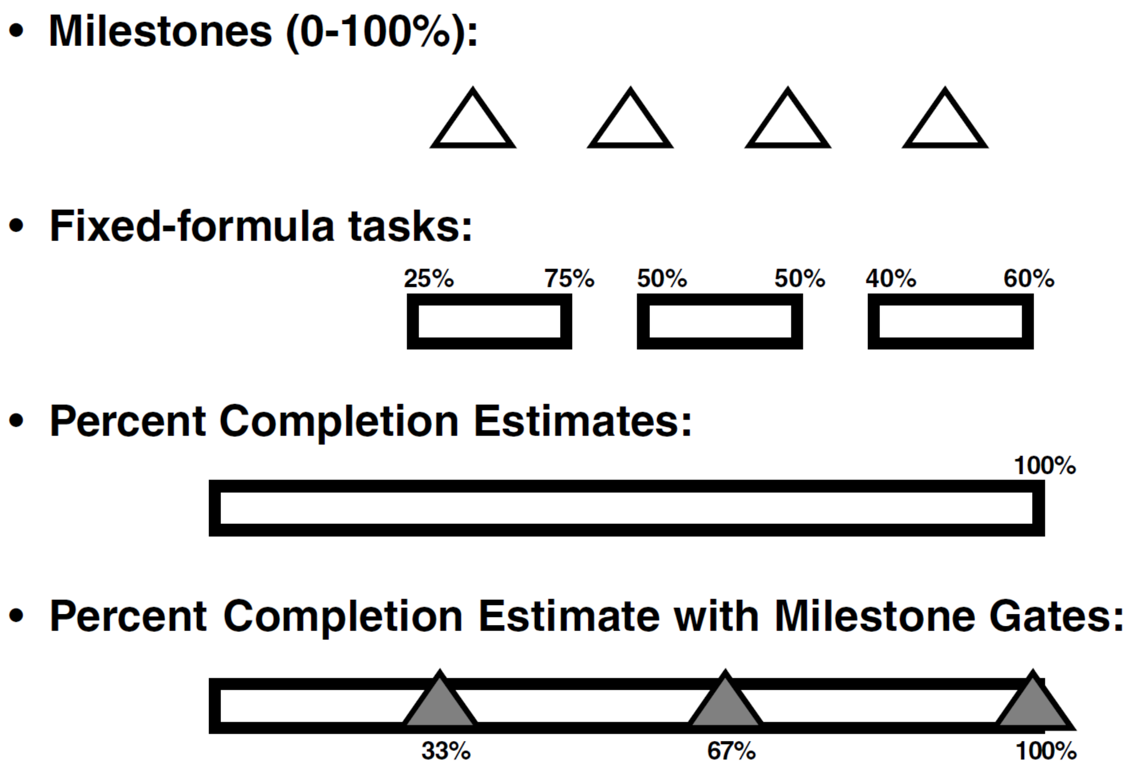


Figure 12. Measurement techniques to convert planned value into earned value (Fleming, Koppelman 2007)

In addition to the above, Lukas (2008) also stresses that postponement of bad news only impedes the implementation of inevitable corrective actions in time. For the same reason, the progress measurement should be kept intact of deliberate management influence (Lukas 2008).

PMI (2005, p. 24) further suggest to consider the task duration in selection of appropriate measurement technique. In progress measurement, tasks that can be completed in one review period require only one measurement and should be preferred. If a task spans over several reporting periods, the milestone approach representing intermediate, tangible outcomes should be preferred. (PMI 2005, p. 24) The management effectiveness and efficiency can be further increased by appropriate allocation of control points (i.e. key review points in the project) (Willems, Vanhoucke 2015).

Determination of physical progress is not possible for all project tasks. Not all of the project tasks produce tangible outcomes that can be measured objectively or are only supportive of nature. A prime example of such work is project management. (PMI 2006, p. 5) Since the earned value of such tasks cannot be quantitatively estimated, the planned value is being allocated for each review period, and in the end of the review period is automatically granted (McConnell 1985). These kinds of support-type project activities are referred to as level of effort (LOE) (McConnell 1985; PMI 2005, p. 11-12; PMI 2006, p. 5). Some of support-type activities, however, are closely related to other tasks. A task that has a direct supportive relationship to one or more tasks (e.g. quality control), for which the earned value is measurable, can be measured as apportioned effort (AE). (PMI 2005, p. 11) In this case the value of the task is proportional to the reference tasks' earned value (McConnell 1985; PMI 2005, p. 11; PMI 2006, p. 5). It is evident considering the nature of LOE activities that schedule variance is always 0 and schedule performance index is always 1 which also reduces the overall schedule variance towards an on-schedule condition (McConnell 1985; PMI 2005, p. 11). Therefore it is also the least recommended method of performance measurement (McConnell 1985). In relation to level of effort type activities, Lukas (2008) bears to mention that LOE constituting over 10% of the budget significantly decreases the accuracy and, thus, reliability of the progress measurement. Nonetheless, a measure including a subjective assessment of progress is better than none at all (PMI 2005, p. 25).

The format, nature and level of detail in reporting should be tailored as per the receiving party's information needs. Intelligibility is of the essence. Too elaborate charts and graphs are useless if they are not understood. Hence, the reports should represent appropriate level of performance for work under the recipients' supervision. When reporting further up in the hierarchy, the reports should be more summarized, highlight only potential schedule slippage and cost overruns, and at need, focus on emerging critical areas in the WBS. (McConnell 1985) Project manager, on the other hand, will need much more detail to enable making necessary adjustments to the project (PMI 2005, p. 22). On the other hand, in-house reporting should always be at least one level below customer reporting. This allows further for variance analysis, to take corrective actions and contingency planning for emerging areas before it is evident for the customer. Nevertheless, any quality or level of reporting is useless if it does not occur in a timely manner. The primary objective of EVM reporting is to forewarn of emerging problems. The purpose of early warning signal is defeated if it does not enable implementation of corrective actions before problems become critical. (McConnell 1985)

EVM data can be reported in numerous ways. Naturally different methods are designed to fulfil the diversity of stakeholder needs. Three of the most common methods are S-curves, tables and bar charts. S-curves have been traditionally used to illustrate the cumulative performance metrics of EVM. An illustration of an S-curve is provided in Figure 13. This kind of representation is generally considered an efficient way to convey a quick view of the overall performance of a task, a control account, or a project. Tabular format, on the other hand, could be useful for displaying the EVM results by project component. An example of such table is provided in Figure 14. One benefit of the tabular format is that it is able to provide a complete, concise picture of what is happening with each element of the project. Hence, an elaborate table could be a logical follow-on and beef up an S-curve with greater amount of detail. (PMI 2005, p. 22)

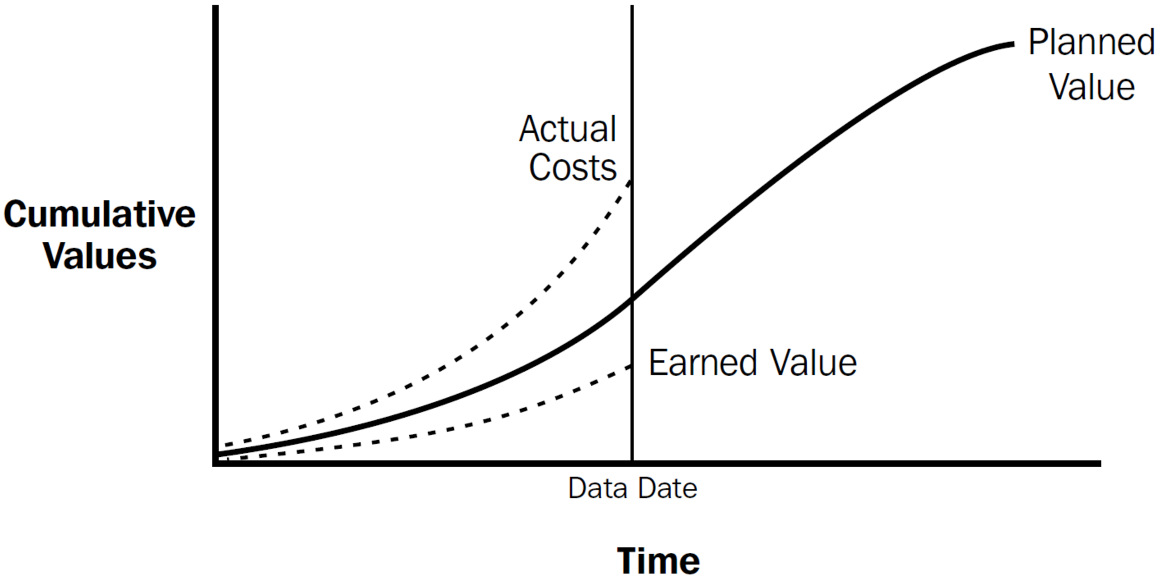


Figure 13. Illustrative graphic performance report (PMI 2000, p. 124)

	Planned	Earned	Cost					Performance Index	
WBS Element	Budget ($) (PV)	Earned Value ($) (EV)	Actual Cost ($) (AC)	Cost Variance ($) (EV – AC)	(%) (CV ÷ EV)	Schedule Variance ($) (EV – PV)	(%) (SV ÷ PV)	Cost CPI (EV ÷ AC)	Schedule SPI (EV ÷ PV)
1.0 Pre-Pilot Plan	63,000	58,000	62,500	–4,500	–7.8	–5,000	–7.9	0.93	0.92
2.0 Checklists	64,000	48,000	46,800	1,200	2.5	–16,000	–25.0	1.03	0.75
3.0 Curriculum	23,000	20,000	23,500	–3,500	–17.5	–3,000	–13.0	0.85	0.87
4.0 Mid-Term Evaluation	68,000	68,000	72,500	–4,500	–6.6	0	0.0	0.94	1.00
5.0 Implementation Support	12,000	10,000	10,000	0	0.0	–2,000	–16.7	1.00	0.83
6.0 Manual of Practice	7,000	6,200	6,000	200	3.2	–800	–11.4	1.03	0.89
7.0 Roll-Out Plan	20,000	13,500	18,100	–4,600	–34.1	–6,500	–32.5	.075	0.68
Totals	**257,000**	**223,700**	**239,400**	**–15,700**	**–7.0**	**–33,300**	**–13.0**	**0.93**	**0.87**

Figure 14. Illustrative tabular performance report (PMI 2000, p. 124)

2.4.4 Within the Control Thresholds

Generally EVM intends to promote project performance control by improving management visibility at the project summary level and limiting the project manager's attention on control actions only when they are required. The control actions are invoked by two concurrent analytical techniques: the variance analysis and the trend analysis. Whereas the emphasis of variance analysis is in detecting meaningful exceptions to the plan to trigger control actions to reclaim the project performance back within an acceptable range, the focus of trend analysis is in enabling proactive control actions to maintain the project performance while the measurements are within the predetermined thresholds. Hence, these two techniques are essentially complementary to each other. (Kim 2014)

The efficiency and effectiveness of EVM obviously culminates on the appropriateness of the thresholds. PMI (2013, p. 148, 198) defines the control threshold as a variance threshold for monitoring a schedule or cost performance specified to establish "an agreed-upon amount of variation to be allowed before some action needs to be taken". It is thus left for the project manager to determine what constitutes meaningful deviations from the baseline plan for the respective project (Kim 2014). Guide to the Project Management Body of Knowledge (PMI 2013) further describes on setting up the thresholds that "thresholds are typically expressed as percentage deviations from the parameters established in the baseline plan" (p. 148) and "the percentage range of acceptable variances will tend to decrease as more work is accomplished" (p. 222). This dynamic change has also been confirmed with statistical methods for EVM performance analysis and forecasting showing that the range between upper and lower limits around a forecast decreases at a chosen level of confidence (Kim 2013; Kim, Reinschmidt 2009; 2010; Lipke et al. 2009). Kim (2014), however, bears to mention that in practice thresholds typically seem to be fixed rather than dynamic.

2.4.5 Assessment of EVM Values

Readings of EVM metrics have been extensively studied, especially on U.S. DoD project datasets. Studies suggest that at point of 20% completion the project final costs can be predicted within ±10% with great confidence, regardless of efforts to manage the situation. (Fleming, Koppelman 2003) Ruskin (2004) further confirms that 80-85% of the degrees of freedom in the project are no longer available at 15-20% completion foreclosing the decision space and possibilities to influence the agreed budget or schedule. However, some authors have expressed inability to generalize the stability results for all projects (Henderson, Zwikael 2008; Lipke et al. 2009). In addition, Stimpson (2007) points out that these implications might not hold true for projects whose scope is not clearly defined and are thus not accurately quantified early in the execution. Fleming and Koppelman (2003) further confirm that cost variances are found to worsen after 20% completion, the point of CPI stabilization, and CPI typically tends to get worse over the course of a project. These findings, and critique regarding the unreliability of EVM with incorrect estimates, indeed stress the importance of preparatory activities in regard to the project and also setting up EVM (Fleming, Koppelman 2003; Stimpson 2007). Not to let the opportunity slip by, it is material to prepare the schedule and budget with care, and select appropriate methods of measurement to avoid overly optimistic progress assessments and false sense of well-being (Ruskin 2004; Lukas 2008). In addition, one should bear in mind that lower degree of criticality of project activities (i.e. more parallel network) is subject to decrease the forecast accuracy. (Vanhoucke, Vandevoorde 2008; Vanhoucke, Vandevoorde 2009)

Method for forecasting and determination on level of performance measurement comes back to the question of benefit-effort trade-off. Some practitioners argue that performance measures on any level cannot be used for forecasting. On the other hand a detailed schedule analysis would induce a heavy burden and disrupting effects for the project team. (Lipke 2009) Jakob and Kane (2004) are of the opinion that SPI/SPI(t) can be considered as true indicators for project performance only on activity level, not on higher levels of WBS (e.g. control account level). Vanhoucke and Vandevoorde (2007) admit that well-performing activities can negate the effects of non-performing activities (masking potential) but come to the conclusion that control accounts on higher levels is the only applicable approach for practitioners. Further the measurement at higher levels is more acceptable for more serial structures, indicating higher degree of criticality of project activities, as opposed to more parallel structures (Vanhoucke, Vandevoorde 2008; Vanhoucke, Vandevoorde 2009).

2.4.6 Forecasting

For time forecasting the Elshaer method integrating the criticality index with ES performance seems to be the most reliable metric in forecasting a project's final duration (Elshaer 2013). However, study on cost and time forecasting methods conducted by Wauters and Vanhoucke (2014) suggest the Elshaer method with significance index to strike a good balance between accuracy and stability.

For cost forecasting the traditional EAC seems to be the most stable method. However, the weighted CPI and SPI(t) based EAC appears to be the most accurate. Thus, the suggested method depends on one’s inclination towards accuracy or stability. Ultimately, the choice of forecasting method is subject to project manager’s preference. (Wauters, Vanhoucke 2014)

2.4.7 The Most Important Earned Value Indicators

Fleming and Koppelman (2009) are of the opinion that CPI and TCPI are undoubtedly the most important EV indicators, in this particular order. Why? Simply because CPI has proven to be a reliable indicator of project financial performance to date. Empirical studies suggest that after the cumulative CPI has stabilized at about 20% completion of the project, the final estimates rarely change over ±10%. That is, CPI gives a reliable early warning signal. (Fleming, Koppelman 2009) Moreover, CPI will progressively stabilize but also tends to decline as the project completes the authorized work (Fleming, Koppelman 2007). Czarnigowska (2008) further concurs that EAC based on CPI has proven to be a reliable lower estimate of final cost overrun.

The CPI reflects only past performance and can be thought of as sunkcosts. Past cannot be changed. Hence immediate corrective actions shall be taken if management is not content with the final cost projection. CPI can also be used for parts of a project or for shorter periods to track periodic results. (Fleming, Koppelman 2009)

The latter, TCPI, works in conjunction with CPI and has its focus in future performance (Fleming, Koppelman 2009). It expresses the required performance to meet the baseline target (Fleming, Koppelman 2009; Lipke et al. 2009). So, if something goes wrong and TCPI indicates cost performance of e.g. 1.25 in order to meet original goals, what kind of performance can be expected? It is not uncommon for projects to assume everything will suddenly go right and reflect unrealistic optimism. Piecemeal EACs are often the norm. However, the authors suggest TCPI of 1.0 or 0.9 to be reasonable. (Fleming, Koppelman 2009) Lipke (2016) further confirms that TCPI (and TSPI) values above 1.1 indicate inability to achieve the targets being tested. Usually people are so anchored in the original estimates that it is painful to admit its elusiveness (Fleming, Koppelman 2009). Chang’s (2001) research on cost-schedule performance index ranges further substantiates the statements on expected performance. In his study the performance was divided into five ranges, from unsatisfactory (1st) to excellent (5th), based on a “reasonable person’s” point of view which the court would deem a satisfactory condition (Chang 2001). Although the concept was originally developed for state engineering projects, Stimpson (2007) suggests that a similar idea could well be applied in construction. Chang's (2001) cost-schedule performance index ranges are available in Figure 15.

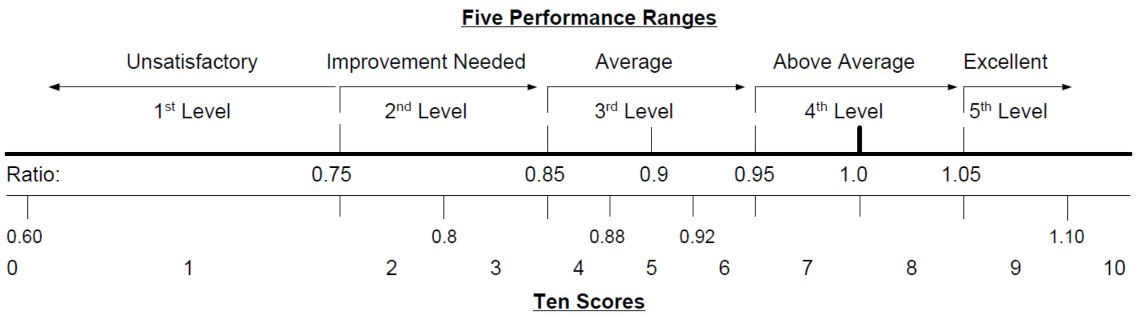


Figure 15. Chang's five performance ranges: ranges and scores for CPI/SPI (Stimpson 2007)

For measurement of schedule performance, the ES metric SPI(t) should be used over SPI since it overcomes the SPI bias (Lipke 2003; De Marco, Narbaev 2013; Vanhoucke 2014).

2.5 Earned Value Management Implementation

Naturally, implementation of a new system or methodology is not always easy. This may be the case especially if the adopter is not familiar with the requirements and actions necessary for successful implementation. The standard EVM practice defined by the U.S. Department of Defense, comprising of 32 guidelines is quite exhaustive, and burdensome to implement (and maintain). Fortunately, utilization of EVM does not necessitate complying with all of the standard guidelines. In the following, recommendations and guidelines for proper but simple EVM implementation are being presented. (Fleming and Koppelman 2006; 2007)

For long has there been debate over the cost and effort to make EVM work, and the limited benefit derived from its implementation (Wilkens 1999; Raby 2000). Therefore, it cannot be stressed enough how important it is to minimize the effort of implementing and maintaining the EVM to maximize the benefit (Fleming, Koppelman 2006). A handful of authors have touched upon the issue of implementing EVM (Wilkens 1999; Raby 2000; Kim et al., 2003; PMI 2005; Fleming and Koppelman 2006, 2007; Czarnigowska 2008; Chen, Zhang 2012; Gershon 2013). However, by far the most comprehensive yet simple rubric for EVM implementation has been presented by Fleming and Koppelman (2006; 2007).

Fleming and Koppelman (2006; 2007; see also 2010), also authors of the PMI's *Earned Value Project Management - Fourth Edition*, have presented a ten-step guide to facilitate and simplify the implementation of EVM. The complete list of ten easy steps, which will be further elaborated below, is as follows (Fleming and Koppelman, 2007):

1. Define the project scope.
2. Determine who will perform the work.
3. Plan and schedule the defined work.
4. Estimate resources and authorize budgets.
5. Define metrics to measure performance.
6. Determine points of management control.
7. Record costs by projects.
8. Measure project performance.

9. Forecast estimates at completion.
10. Manage changes to the project baseline.

The implementation naturally starts with defining the scope (Fleming, Koppelman 2006; 2007). Decomposition of work to manageable level is the first step in establishing a performance measurement baseline (PMI 2005, p. 23). Obviously measurement of progress is not possible if the work constituting 100 percent of the project is not defined. When defining a project scope is not possible with absolute precision, educated assumptions have to be made in order to allow decomposition, planning, scheduling, and estimation of work with some degree of certainty, and ultimately to set a baseline. Proper scope definition already in the beginning of the project also prevents scope creep. Defining the scope is easiest done by means of a WBS which is a fundamental part in integrating the schedule and costs. (Fleming, Koppelman 2006; 2007) In relation to EVM, it is of particular importance that creating a WBS involves assigning unambiguous management responsibility. That is, each control account must be managed by only one control account manager or team. (PMI 2005, p. 24) As a fundamental part of EVM, the benefits and guidelines for producing a WBS are discussed in Section 2.4. (Fleming, Koppelman 2006; 2007)

Secondly, one should determine who will perform the defined work. The question is not only whether the work will be performed by experienced or inexperienced people but more importantly a make-or-buy decision. That is, whether some parts of the work must be procured. The significant difference is that procurements are based on non-forgiving legal arrangements, and changes after contract award come with a price. Therefore, the identification and responsibility assignment of procured work is essential, and further facilitates management of work packages. The progress of the defined work has to be reported and measured alike whether it is performed inside or outside the project organization. (Fleming, Koppelman 2006; 2007)

Third, the defined work has to be planned and scheduled. A formal scheduling process is probably the most critical single tool required for implementing earned value. A formal scheduling system is a vehicle representing the project scope, planned value and resulting earned value. The scheduled work and its authorized budget constitute the planned value, and the completed planned value further constitutes the earned value, and, thus, must be measured with same metrics. Both PV and EV emanate from the project master schedule which reflects the project manager's baseline for everyone to follow. Preferably in complex projects critical path methodology (CPM) should also be employed to enable aggressive management of high-risk tasks (those on critical or near critical paths) when negative earned value schedule variances occur. (Fleming, Koppelman 2006; 2007)

After the schedule has been prepared, the next requirement to form an earned value baseline is resource estimation and authorizing budgets (Fleming, Koppelman 2006; 2007). Resourcing is the last step in establishing a time-phased budget (PMI 2005, p. 24). Hence, resource requirements are estimated for all tasks or activities within each WBS element, and shall yield in a reasonable and achievable value. The requested resources are then being assessed and approved as authorized budgets which shall not contain any management reserves or contingencies. Viability of the project baseline indeed hinges upon the achievability of the authorized budgets. (Fleming, Koppelman 2006; 2007) Contingency reserves are, however, added to the project cost estimate (authorized budgets) to arrive at a cost baseline against which the performance is being measured (PMI 2008, p. 177).

Further, to be able to gain earned value, metrics must be determined in order to convert it from the planned value. Hence, earned value has nothing to do with the actual costs. Metrics are set up to quantify the physical completion of authorized scope and the associated authorized budget. Fleming and Koppelman (2006; 2007) suggest one of the following discrete measurements depending on the task: milestones (0-100 percent measurements), fixed formulas (e.g. 25-75, 50-50 or 40-60), percent completion estimates, or percent completion estimates with milestone gates. Although there is nothing wrong with percent completion estimates, they are inherently subject to potential gaming and should be used with caution. Other types of performance measurement are also possible if seen appropriate. (Fleming, Koppelman 2006; 2007) However, to allow assessments of progress to yield comparable earned values to the planned values and the actual costs, it is suggested to adhere to the measurement plans during the project execution (PMI 2005, p. 25). After all, "earned-value project management is nothing more than managing a project with a resource-loaded schedule" (Fleming, Koppelman 2006; 2007).

Next up in the list is determination of management control points, also referred to as control account plans (CAPs). The CAPs can be thought as subprojects within the project, and can be placed anywhere in the WBS considering the sum of all caps constitutes the total project. (Fleming, Koppelman 2006; 2007) Furthermore, Fleming and Koppelman (2006; 2007) remind that each CAP must contain the following elements: 1) a unique statement of work, 2) a schedule for performance, 3) a finite budget, and 4) a person in charge, responsibility for the performance of each CAP (i.e. a CAP manager). Similarly control accounts determine the minimum level for which allocation of costs should be enabled (Fleming, Koppelman 2006; 2007).

Now, to be able to manage the costs of the project, the costs must be recorded by project and further aligned to the authorized project budgets, or at very least to CAPs (Fleming, Koppelman 2006; 2007). The higher the detail in which costs are being recorded, the higher the rigor at which cost performance can be managed (PMI 2005, p. 25). The earned value can then be compared to the actual costs in order to determine the single most important metric for any project employing earned value, that is, the Cost Performance Index. Although vast amount of companies nowadays measure their performance on weekly basis, one thing must be well understood. (Fleming, Koppelman 2006; 2007) The actual costs (e.g. direct labor dollars, indirect costs, purchased articles and travel) are usually not available on weekly basis, and hence, some projects may find the use of labor hours or material quantities to be adequate or preferable (PMI 2005, p. 25; Fleming, Koppelman 2006; 2007). Consequently, to enable reliable weekly reporting, the accuracy and correctness of weekly labor reports is critical. To minimize such errors and enhance reliability of earned value reporting, employment of an automated direct labor-tracking system could be useful. (Fleming, Koppelman 2006; 2007)

Then, the project performance should be measured as per the set performance metrics to determine the earned value. The cost and schedule results must be monitored against the authorized baseline. (Fleming, Koppelman 2006; 2007) Earned value is a management-by-exception approach after all (PMI 2005, p. 21). Variance thresholds should be established in the planning phase and attention should be focused on the exceptions to the baseline (PMI 2005, p. 25). Moreover, tasks behind schedule should be assessed as to its criticality. Late tasks on critical path impose greater risk and should be a priority to get back on track. Low-risk tasks or tasks with positive critical path float do not require additional resources. (Fleming, Koppelman 2006; 2007) However, extra caution should be exercised in reviewing the performance data on higher levels because compensating good performance can easily mask poor performance at lower levels (PMI 2005, p. 25).

History advises that absolute cost overruns are typically nonrecoverable and percentual overruns tend to deteriorate unless aggressive mitigation actions take place. Hence, particular emphasis should be placed on the cost readings the employment of earned value provides, especially after project completion of 15% whereafter the cost efficiency factor has been found to stabilize. (Fleming, Koppelman 2006; 2007)

Next, one must continually forecast the project final costs (and time) based on the measured performance to keep the management updated and poised to take corrective actions when necessary. Indeed, the incurred costs are nonrecoverable and any improvements in performance must come from future work. Fortunately, earned value enables forecasting the cost (and time) estimate at completion without additional effort. (Fleming, Koppelman 2006; 2007) The EVM forecasts should not be taken as is but rather function of the forecasts is to compare their objective values with other management estimates offered by project team members (PMI 2005, p. 25). In case of considerable differences between other forecasts, reconciliation of EAC(€) and other estimates might be necessary. Nevertheless, to base the assumption of future performance on realized cost efficiency rate (CPI) is found reasonable. As already indicated, studies suggest that CPI does not typically vary more than ±10% once the project is 20% complete which could, thus, be considered as the early action threshold. (Fleming, Koppelman 2006; 2007)

Last but not least, an integrated change control process shall be established to maintain integrity of performance measurement baseline throughout the project (PMI 2005, p. 24; Fleming, Koppelman 2006; 2007). Through a formal change procedure, the scope is maintained by rejecting changes or incorporating the approved changes into the project baseline in a timely manner. Each change request must be carefully addressed and controlled in order to maintain the initial baseline valid. Maintaining the approved baseline may thus prove to be as challenging as defining the initial project scope. (Fleming, Koppelman 2006; 2007)

In general, there are two basic reasons to change the performance measurement baseline. First and foremost, change in scope of work shall be reflected in a revised baseline. Second, a revised baseline can be justified if poor past performance renders the current baseline worthless as a comparator for measuring the present performance. (PMI 2005, p. 24)

It is apparent that successful implementation of EVM requires additional practices and/or processes in planning, execution and control (PMI 2005, p. 2). With help of available contemporary computer tools, the implementation could be thought as a relatively simple "cookbook" procedure (Wilkens 1999). However, it is not simply a matter of introducing the methodology but it is also associated with overall organizational approaches (e.g. continuing top-level management attention and facilitating support systems) (Kim et al. 2003). Moreover, it might be influenced by abiding cultural issues. Naturally, reluctance to report adverse information or excessive optimism for recoveries from cost overruns in order to protect the project (or careers) will impede effective project management. (Chen, Zhang 2012) To highlight the issue, Christensen et al. (1992) claimed that the accuracy of EAC forecasts is of lesser importance than resolving these "abiding cultural problems".

Generally, to enable the implementation of earned value, all stakeholders have to be convinced of the value it provides. Usually the opponents will cite the cost and effort of implementation, and resulting limited benefit. Proponents on the other hand refer to the overall cost savings, improved analysis, communication and control. (Wilkens 1999; Raby 2000) Hence, the project managers have to be convinced of the value and necessity of earned value to facilitate in achieving project success. Similarly, the management should be convinced of the benefits of accurate costing and, at higher level, allowing better portfolio and resource management to meet key company objectives. (Gershon 2013) Properly prepared project plan enables earned value analysis with nominal additional effort (Lukas 2008). In regards of training, more emphasis should be placed on when, why and how to use earned value instead of the equations (Gershon 2013).

3 Assessment of Current Situation

In order to determine the necessary changes to implement EVM in the organizational level, the current situation and EVM related processes have to be well reviewed. In the following, the current practices in Caverion Industria Project Services are considered first from practical point of view by describing the typical field of work and common project life-cycle. Second, the organizational guidelines will be reviewed in order to describe the project management practices and processes in relation to cost management, and especially EVM. Particular emphasis will be placed on areas which will be affected by implementation of EVM methodology. The following review and analysis is written in light of my own experience and various discussions with CaIn PS project personnel.

3.1 Typical Projects

Caverion Industria Project Services operates on field of industrial construction and maintenance, and in particular industrial mechanical installations. The main field of know-how is thought to be in project management and piping installation, including prefabrication. The project scope mainly consists of piping installation (inclusive of prefabrication and testing) of power or process plants but may also include other mechanical installation such as equipment or steel structure installation. Depending on the project, Caverion may also provide to procure the piping materials or provide design services. In general, parts of the project scope which are not mechanical work are subcontracted. The most common parts of work that are subcontracted are supportive or specialized of nature. Supporting subcontracted works generally include scaffolding, lifting services and temporary site facilities. Other more specialized subcontracted works include insulation, surface treatment, heat treatment (for welding), non-destructive testing (NDT) and refractory works. However, parts of mechanical installations may also be subcontracted if seen necessary. Since the projects usually include various phases and several disciplines, the project management naturally involves management of these interphases.

Life cycles of the projects consist of several different phases. Normally the project life cycle starts with a lead which may develop into an opportunity. The opportunity is followed by offer calculation but in between a bid/no bid decision has to be made on the grounds of a risk analysis. Preferably the potential project manager would be involved already in this phase. Potential offers are based on information and templates provided by the customer. The offer is naturally followed by tendering phase which potentially leads to finalization of the contract. The project handover to project organization occurs only after the contract has been signed.

For the project manager the project concretely begins with project planning after the handover. Preliminary resource reservations have been made already in the tendering phase but the actual project organization is being formed by the project manager in the project planning phase. Rough scheduling and cash flow forecasts are being performed. Binding resource reservations and procurement will be done as per the rough schedule and work planning. If a project schedule is required by the customer, usually a formal document is being produced. The project execution shall start as per the contract schedule.

The actual project execution involves variety of different activities. First, the site has to be prepared to enable sufficient working conditions. This may include for example set up of temporary site facilities and a data-communication link. Thereafter, the work with tangible project deliverables may begin. As indicated above, the variety of different installation activities is multifold.

The installation work is very phase-oriented by nature. That is, installation of piping or equipment consists of different serial phases meaning serial use of resources. However, the constructions sites are also loaded with parallel operations meaning that many pipelines and equipment could be installed at the same time and many of them in different phases. The phase schematic for piping installation is as follows:

1. Prefabrication: installation, welding and post weld heat treatment (PWHT)
2. Nondestructive testing (NDT) and documentation of prefabrication work
3. Storage in prefabrication shop
4. Transportation to paintshop
5. Surface treatment and inspection
6. Transportation to site
7. Storage at site
8. Hauling of prefabricates and installation material in site
9. Installation and welding
10. PWHT and NDT inspection
11. Line walk (inspection)
12. Pressure testing and inspection
13. Reinstatement
14. Touch-up painting
15. Insulation
16. Final inspection and documentation.

The process for equipment and steel structure installation is not as complex but is similar of nature. When the physical works have been completed, the site is being decentralized.

The most common issues in the actual work are lack and modification of design, late delivery of installation or prefabrication materials and compact size of the construction sites. Especially due to the tightness of the construction sites, the installation sequences need to be carefully planned prior to execution of work. Late delivery of materials or lack of design often causes impediment to the work and changes to installation sequence. Consequently, changes to sequence and late modifications to design are likely to cause rework, especially if they are not communicated and planned in time.

Measurement of progress is usually performed according to customer requirements. If customer does not have particular requirements for measuring the progress, the work is typically determined with eyeball estimates, i.e. subjective percent complete estimations, of site supervisors and documented in their own lists. The only discipline which has a consistent method of measurement is piping installation and welding work. The progress of piping installation (and also prefabrication) is generally determined through welded diameter inches (WDI), often being the only objective indicator of physical progress that is being followed. Welding data is also the only mentioned measure of progress in the Project Handbook. Since all of the installation work merely culminates on piping installation, the progress of welding work (regardless of other disciplines) is thought to be a reflective estimate of the total progress. At the moment no production control system or comprehensive progress measurement calculations practices do exist that would objectively measure the full scope of work if not provided by the client. The motivation for tracking the progress seems merely external, that is, to fulfil the customer needs rather than to support the project management.

The project execution phase ends to a final settlement and handover of deliverables to the client. The handover includes the documentation prepared in relation to the deliverables. The final settlement also includes settlement of unsettled changes of scope and financial claims. Finally, the project closure ends the life-cycle of the project.

3.2 Organizational Guidelines

At the moment the organization has only one guideline document, the Project Handbook (originally in Finnish *Projektikäsikirja*) which is being followed to a varied degree. This manual describes the project management basics at relatively detailed level but however does not provide sufficient supporting tools to manage the project efficiently. Especially essential tools for cost and scope management are non-existent. More importantly, the integration of scope, time and costs is not discussed. Consequently, there is a definite need to fill this void.

Indeed, it may well be recognized that the project management maturity in the organizational level is not of desired grade. Some of the guidelines presented in Project Handbook do not define the tools or processes in detail which allows for variety in managing the project. This has been the problem especially in cost management and forecasting but also for scope and time management. Usually scheduling and scope management have been realized with temporary solutions in order to fulfill customer requirements rather than to support the project management itself which evidently evades the purpose. Therefore necessary processes, especially in relation to project planning, to support EVM need to be established.

The project financials are managed with a tailored software called V10. The project manager is obliged to establish the budget and forecasts on a standard breakdown template which is further compared to the actual costs. The breakdown is as follows:

- Invoicing (income)
- Materials (cost)
- Design (cost)
- Prefabrication (cost)
- Installation (cost)
- Subcontracting (cost)
- Project management (cost), and
- Equipment, facilities and other variable costs (cost).

In regards of EVM, this arrangement has certain integral flaws which vitiate the purpose of earned value. First, the arrangement does not allow monitoring the financial status of each element (or control account); the financial status can be monitored only on project level. Second, although the budgets are allocated for predetermined review periods, the allocation is not integrated to an existing schedule but allocations are merely estimates determined by the project manager which allows for potential gaming and counter-productive bias in forecasting. Third, the quality of the breakdown itself is debatable but nonetheless the breakdown does not relate to an existing scope statement or WBS.

Further shortages can be noticed in relation to scope management. Typically the formal documentation in relation to scope (e.g. scope statement, WBS and scope baseline) is non-existent which prevents from integration of the project management triangle (i.e. scope, schedule and cost). Usually the scope is best described in the contract and engineering documentation (e.g. material take-off lists, i.e. MTOs) but it is not appropriately linked to the schedule and costs. Lack of proper documentation of scope and a non-existent scope baseline further pre-empts the entire change control process. A scope baseline is *de facto* imperative in order to establish a competent plan for the project and control the changes to the baseline.

For scheduling the Project Handbook suggests use of MS Project or Planet. Basic guidelines for constructing and updating the schedule and progress are being provided. However, the integration of schedule to the existing scope documentation and cost management is still lacking.

The unit is, however, going through a whirlwind of reforms. One big change to the existing situation is the changeover from V10 to SAP Project System (SAP PS). This is to be implemented during 2018. Implementation of SAP PS enables more possibilities from definable WBS to integration of other systems (Nabavi, Rouhani 2009). Especially incorporation of a tailored WBS and setting control accounts enables to practice EVM more efficiently. Similarly, the labor tracking system Jotbar should allow incorporation of WBS. Another objective pointed out by management is to incorporate Building Information Model (BIM) as part of our current practice which could also be of assistance in monitoring and reporting the progress.

4 Results

This chapter presents the results of this thesis. Results are based on careful literature review and assessment of current practices. The results are twofold and, thus, separated into two distinct sections: The Earned Value Management Implementation Rubric and Tool Development and Description.

4.1 Implementing Earned Value Management

One of the two primary objectives of this work is to provide a guideline for implementation and practice of EVM methodology. The earned value practice has its basis on exhaustive standard provided by U.S. Department of Defense comprising of 32 distinct guidelines. However, utilization of EVM does not necessitate to comply with all of the standard guidelines. In the following, benefits of EVM, general considerations, prerequisites, recommendations and guidelines for proper but simple EVM implementation and practice are being presented.

4.1.1 Ex Ante

Practicing EVM as part of project management has shown to yield undisputable benefits. The cost-benefit ratio has always been the topic of debate but given the guidelines to stripped-down way to implement the methodology, the results seem to suggest that the benefits provide more value than that of the cost. As originally intended, use of EVM provides an objective and consistent way to evaluate project performance enabling better cost management, improved financial control, an early warning indicator for corrective actions and forecasting of project costs. However, and all the more if project management maturity is not of high-grade, implementation of EVM methodology provides substantive additional value in managing the project. It is also been noted that in such an engineering oriented business the numbers speak better for themselves than empty phrases.

First of all, use of EVM requires integration of scope, schedule and costs. Therefore implementation of the methodology places greater emphasis on planning processes providing valuable insight of the project. Similarly the integration of cost and plans provides additional value in allowing better management and control of smaller entities. Consistent and simplistic way of reporting also increases management awareness. Besides, considering the additional value gained through thorough planning and increased management awareness, it also allows for enhanced communication and increases stakeholder confidence.

Although EVM is a useful tool, it is not beatific. The users should be aware of the following three integral characteristics of EVM to be able to use EVM according to its purpose. First, it only considers the past performance and reflects a linear extrapolation of current tendencies. Second, EVM does not take into account risk or other performance factors. And third, as it only produces a rough estimate of project outcome, it is not itself a tool for forecasting. This means that managing the project is always subject to expert judgment of the project team and in particular project manager. EVM only produces useful data that can be used to better manage the project but does not guarantee good results. Conscious use of earned value, however, can assist in achieving better results.

4.1.2 The Earned Value Management Implementation Rubric

In order to employ EVM successfully, certain tools, processes and infrastructure are required. However, the first step is to consider implementation of the practice as an organizational approach. The management and project team members have to be familiarized to the methodology and its prerequisites, convinced of the value it provides, and engaged to act incumbently. It is suggested to organize training sessions to management and project personnel as well as for subcontractors to enable sufficient assimilation of the methodology and how it is practiced. In order for EVM to functions as intended, it is paramount to exterminate the abiding cultural problems in relation to subjective progress reporting and gaming, if any, and engage to report progress objectively. Objective reporting sets out the basis for accurate performance measurement and forecasting.

Now, after the rubric of Fleming and Koppelman (2007), the first necessary area of improvement is scope management. A process needs to be established which produces a formal definition of scope which is easiest done by means of a WBS. WBS can be considered as the most important single tool to support EVM since it is imperative to enable the integration of costs and schedule. WBS is the backbone of scope management which sets up the basis for a time-phased budget. When the scope is properly defined, the schedule and budget can be later produced on the basis of WBS.

WBS is a hierarchical decomposition of project work necessary to accomplish the project objectives and produce deliverables. The process of decomposition project deliverables into smaller components shall continue until the cost and duration of work can be reliably estimated and managed. The project WBS should be established already in the tendering phase to support budgeting. Now, in order to facilitate process of producing a WBS and also to create a foundation for EVM, producing a deliverable oriented high-level WBS template (at least two levels) with defined control accounts is suggested. The template should rather cover all kinds of works that can be expected in typical works for the organization. In developing a project specific WBS on the basis of the template, the unnecessary elements can be excluded. A high-level template with control accounts would enable a default cost allocation in which case the efforts necessary for cost allocation would be minimal. Although vast amount of detail in WBS can constitute an overwhelming burden in managing, controlling and reporting, too much detail is preferred over too less. Rather small work package sizes (40-80 hours) should be preferred to support the 0-100 measurement approach in order to minimize the measurement effort. Lastly, each WBS element must have one person clearly accountable for its completion.

In addition to accountability, it has to be determined that who will perform the work. The question is not exactly about who in particular will perform the work but is rather a make-or-buy decision. If parts of the works are being procured or subcontracted, the subcontractor must be introduced to the EVM practice and obliged to report and measure the progress accordingly. It would also be advantageous to prefer unit rate contracts over time and material based contracts and require binding offers from subcontractors already in tender phase to be able to lock down the budgets.

The planning and scheduling should also commence in tender phase. The schedule shall be based on the WBS which allows the integration of schedule and cost. Eventually the schedule system shall represent the total scope of work, planned value and resulting earned value. In order to retain the comparability, the planned value and earned value have to be measure with the same metrics. Usually contribution of the project team, team leaders and supervisors is necessary to produce a schedule of sufficient detail. Software-wise use of MS Project is suggested due to better compatibility possibilities.

After preparing the schedule, the integration of costs to form the baseline is performed by estimating the resources and authorizing the budgets. Resource requirements are estimated for all tasks and/or activities within each WBS element. The outcome must yield in a reasonable and achievable value, and shall not contain any management reserves or contingencies. Ultimately, the viability of the project baseline hinges upon achievability of the authorized budgets. Therefore contribution of the project team in estimating the resources is of utmost importance to ensure the achievability of the budgets and project team's commitment to the plan. Last, subject to project manager's preference, contingency reserves may be added in order to form the cost performance baseline. Finally, when the scope of work has been scheduled including tasks corresponding to each work package, work packages have been budgeted and potentially contingencies added, the costs and schedule constitute an integrated entity and the EVM baseline is set.

Having set the baseline, metrics need to be defined to measure the performance and determine earned value. The earned value naturally hinges on how the progress is being measured. The choice of discrete measurements should be subject to the character and size of the work package. However, percent completion estimates should be avoided to minimize the effect of potential gaming and bias, and used only if no objective indicator to measure the work is available. Milestone measurement (i.e. 0-100 approach) is recommended for work packages of smaller size and short duration, preferably not longer than one measurement period. For work packages of bigger size and longer than one measurement period, the percent completion estimates with milestone gates is suggested which along with specific milestone measurement possesses the ease of administration and built-in checks. An exemplary application of its use would be a pipeline installation: pipes installed = 25%, pipes welded = 50% and pipeline tested = 25%. Similar approach is also suggested for equipment installation since the work phases are usually discrete which does not allow for continuous workflow. If such approach is being used, the predefined criteria for each milestone and percentage shall be defined by the project manager with consultancy of the assigned person in charge. It would also be useful to take advantage of objective measures that are regularly updated and readily available. This is the case especially for welding work which is frequently documented and for which the scope of work is predetermined in work planning phase.

Some of the project tasks do not produce tangible outcomes and determination of physical progress is therefore impossible. For such tasks, e.g. project management, the earned value shall be determined with level of effort technique. In that case the planned value is allocated for each review period and is automatically granted. However, if such a task has a direct supportive relationship to another task for which the earned value is measurable, the value can be apportioned to the reference task earned value. This approach is referred to as apportioned effort. Lastly, it is suggested that the degree of level of effort support type project activities, whose measurement is based on duration rather than actual progress, should not constitute over 10% of budget in order to maintain the measurement of progress reliable.

After definition of performance measurement metrics the determination of management control points, i.e. Control Account Plans (CAPs), shall take place. Control account plans are selected management control points in the WBS where the measurement of performance will take place. They can be thought as measurable subprojects that sum up to the total project. Typically control accounts are the intersections of the functional organization and the project organizational hierarchy. As per Fleming and Koppelman (2006, 2007) each CAP should include 1) a unique statement of work, 2) a schedule for performance, 3) a finite budget, and 4) a person in charge (i.e. a CAP manager). Also, since the measurement of performance occurs at control account level, the costs allocation must be possible for each control account. In relation to the WBS template, it is would be useful to predetermine the CAPs in the WBS template to ensure the viability of cost allocation and minimize the efforts required.

Recording of costs is one of the EVM cornerstones. To enable the performance measurement of project key areas, the recording of costs should be aligned to the authorized budgets, or at very least to CAPs. Hence, SAP PS and V10 have to be prepared on the basis of the WBS and predefined CAPs. Although the performance measurement is usually performed on a weekly basis, the actual cost updates in the accounting system generally occur on monthly basis. Hence, adjusted actual costs have to be estimated through weekly labor reports and other resource related documentation to determine the weekly performance. In order to minimize the efforts in relation to estimation of adjusted actuals, use of an automated labor-tracking system is suggested. Labor-tracking system (Jotbar) used in Caverion Industria does not consider the wages of each employee since the payroll computation takes place elsewhere but a good enough estimate can be calculated with an average wage of a resource which is also the practice in budgeting. While it is true that subcontractors are usually not inclined to provide working hour information for commercial reasons, it would be best to oblige it as per contract. For sake of consistency, method for assessing the adjusted actuals for each element and discipline in the project should be determined prior to project start.

Now that all EVM related prerequisites have been cleared, one can now measure the project performance. As earned value is a management-by-exception approach, the cost and schedule measures are being monitored against the authorized baseline. The performance measurement itself is performed in the Excel-based EVM Tool developed for the sole purpose. The EVM Tool will be further described in Section 4.2. The physical progress and actual costs are being recorded in the EVM Tool for each control account in the respective tabs and the tool calculates all the performance measures for each control account and the total project. Particular emphasis should be placed on tasks which are of higher risk (delays and critical path). It has been shown that absolute cost overruns are typically nonrecoverable and percentual overruns tend to deteriorate unless aggressive mitigation actions take place. Therefore, as the CPI is inclined to stabilize at 20% completion, particular emphasis should be placed on the earned value costs readings after 15% completion to enable potential mitigation measures when the leverage would be the greatest. Assessment of performance and managing with earned value is elaborated in Section 4.1.3 and further guidelines for interpreting the produced EVM data is discussed in Section 4.1.4.

Determination of EVM performance metrics also enables forecasting. Since the incurred costs are nonrecoverable, any improvements in performance must come from the future work. The EVM forecasts are developed with the EVM Tool on the basis of calculated performance measures. Based on the latest research on earned value theories, the EVM Tool provides eight cost forecasts and three time forecasts which are based on different performance factors providing a range for more accurate forecasting. The CPI, however, does not typically vary more than ±10% after 20% completion which can thus be considered as the early action threshold.

Projects are unique of nature and naturally subject to changes. However, integrity of performance measurement baseline needs to be maintained throughout the project. Changes to the original plan have to be carefully controlled and therefore a formal change management process has to be in place. First, a change management process assures that changes are addressed properly and also incorporated into the current plan. Second, this process allows allocation of potential contingencies or reserves. In case something unexpected occurs and the change is being accepted, contingencies are then allocated for the corresponding work packages and PV curve will be modified accordingly. Hence, accepted changes need to be well documented and updated to the EVM Tool as an update to the baseline. Additionally, in case the current baseline proves as a worthless tool in measuring the present performance, a revised baseline is justified.

Finally, the tailored implementation rubric can be described as follows:

0. Ensure sufficient understanding of EVM for the project personnel.
1. Define the project scope and produce WBS.
2. Determine who will perform the work.
3. Plan and schedule the defined work in MS Project.
4. Estimate resources and authorize budgets.
5. Define metrics to measure performance.
6. Determine points of management control.
7. Record costs by projects in V10/SAP.
8. Measure project performance with EVM Tool.
9. Forecast estimates at completion with EVM Tool.
10. Manage changes to the project baseline.

4.1.3 Management by Exception

Management by exception practically means that control actions are only invoked when meaningful predetermined deviations to the baseline are being noticed. The project manager can primarily focus on execution of the project which greatly contributes to the efficiency and effectiveness of project management. However, the efficiency and effectiveness of EVM is obviously governed by appropriateness of set thresholds. Too narrow ranges enforce unnecessary attention and management may be inundated with data. Too loose ranges, on the other hand, may let the early opportunities to invoke control actions slip by. EVM is about early warning indicators after all. Ultimately it is subject to the project manager and respective supervisors (CAP managers) to determine appropriate thresholds from task to summary level.

The two complementary and concurrent analytical techniques, variance analysis and trend analysis, shall be used to control the performance. Whereas variance analysis triggers control actions when the performance exceeds the predefined thresholds, trend analysis shall be used to enable proactive control actions in order to keep the performance in the acceptable range. The variance thresholds are usually defined as fixed percentage deviations from the baseline parameters although acceptable range and possibility to influence the project outcome tend to decrease as more work is being accomplished. Therefore it may be useful to dynamically adjust the thresholds as the project progresses. For trend analysis simple thresholds do not typically exist but a comprehensive understanding should be built on the basis of graphs and tables representing patterns and trends in periodic and cumulative data. Hence, the proactive trend analysis shall be subject to careful controller attention. The controller may have to drill down to lower levels to further analyze the underlying cause of higher level trends.

Last, although EVM does provide the early warning indicators that invoke control actions, it does not reveal the causes of performance. Ultimately the project manager and project team having the best information and insight need to decipher where the problems lie to be able to recommend or take appropriate corrective actions. The explanations, interpretations and control actions shall be reported for higher management to improve management visibility.

4.1.4 Guidelines

When employed correctly, EVM as a tool provides an objective outlook where the project stands. The tool provides a multitude of key metrics and graphs that can be used to analyze the performance and forecast project outcome. However, employment of EVM itself is not a guarantee of good results or elimination of cost overruns or schedule slippages. Moreover, it is not a tool for forecasting. Rather, it is a tool to assist in determining the project status, total duration and costs for better decision making. Hence, the provided information should be used according to its purpose. One should not take the information as given but as additional information that the project management can use to better manage the project costs and assist in making right decisions. Therefore it is important that the project management has the expertise to interpret the provided information in order to allow better decision making. Ultimately it is the project manager that has to use its expert judgement on the basis of given data in making the decisions. Literature suggests consideration of the following guidelines to exploit the additional value provided by EVM practice to the fullest.

Reporting

Reporting the measured progress should be based on reporting needs. The focus of reporting should be adapted as per the audience. Generally management has to monitor the overall status of the unit which usually is involved in handful of projects at the same time. Therefore the focus should be on overall progress, the observed key issues and areas of particular interest. This includes the key progress measures and best available time and cost forecast for the overall project, and potentially key metrics in relation to observed difficulties and predetermined areas of interest. Project teams and team leaders, on the other hand, need more detailed reporting in relation to their own work and responsibilities.

Reporting is not useful unless the audience is able to understand it. Hence, in order to increase reporting effectiveness, the reported metrics and figures should be presented in the way most meaningful to the audience. Usually management holds a better understanding of finance and therefore is also interested in absolute monetary values in addition to relative metrics. For the project teams, if possible, it may be useful to convert the monetary values into more tangible units, for example into working hours or units to be completed.

Last, and most importantly, all kinds of reporting is useless unless it is on time. The main objective of EVM is to provide early warning indicators to enable timely implementation of corrective actions. Timeliness is of the essence. Efficient progress measurement and reporting is imperative to enable the early adaptation to prevailing circumstances.

Assessment of Produced Values and Analysis

Eventually managing with Earned Value culminates in assessment of the produced information. Sound basis has to be established with careful set up of baseline schedule, budgeting and selection of appropriate and accurate progress measurement methods. On this basis reliable metrics, performance measures and ultimately forecast can be produced. First, EVM is a tool for cost management and therefore the CPI is indeed the most important performance measure. Studies on U.S. DoD project datasets suggests that CPI tends to stabilize at the point of 20% completion. Similarly it is axiomatic that possibilities to affect the project outcome decline as the project progresses. Therefore particular emphasis shall be given at the point of stabilization to see where the project is headed and exploit the situation when there are the best possibilities to influence the project outcome. Hence, this would be a natural time to set a control point to allow the stakeholders make significant decisions over the future directions of the project. Further, studies on the same datasets suggest that the project outcome can be predicted within ±10% with great confidence. Moreover, CPI also tends to worsen after 20% completion which further underlines the significance of project planning and the outset. This should be considered especially in pursuance of assessing the corrective actions to avoid reflecting overly optimism to the project outcome and false sense of well-being. Another consideration is that EVM and CPI only reflect the past performance and therefore other indicators and knowledge in relation to potential future performance shall be weighed. Later in the project periodic CPI can be used to more accurately monitor what kind of influence the made decisions have on the performance.

The other emphasized future reflective metric TCPI should be used in analyzing the required performance to meet the baseline target. TCPI values above 1.1 have been indicated to foresee inability to achieve the targets being tested. Therefore TCPI over 1.1 shall be considered as an alarm bell for immediate corrective actions all the more in as much as CPI tends to worsen over time. In addition, it could be reasonable to acknowledge the prevailing CPI trends, with particular emphasis on the latest periodic CPI's, in judging the achievability of the given TCPI.

Industrial mechanical installation projects usually consist of several if not tens of parallel activities which also decreases the forecast accuracy. Therefore, as also suggested by research in relation to EVM, more accurate forecasting methods should be used to provide more accurate forecasts. Also given the critique that SPI and SPI(t) can be considered as true indicators for project performance only on activity level, this holds especially true for time forecasting. However, considering the appropriate EVM cost forecast, depending on project manager's inclination towards stability or accuracy, the traditional and weighted CPI and SPI(t) based forecasts, $EAC(€)_2$ (formula (24)) and $EAC(€)_8$ (formula (30)) respectively, should be preferred.

4.2 Tool Development and Description

This section describes the development of the EVM Tool and the definite outcome. The structure of this section is threefold. First, theoretical basis of the tool is being unfolded. Second, the tool requirements are being assessed. Third, the tool developed on the basis of defined requirements is being presented.

4.2.1 Basics and theory

The second primary objective of this study is to provide an EVM Tool which allows consistent cost monitoring and forecasting. During the last decades a lot of research effort has focused on developing more accurate methods of performing cost control by extending the theoretical basis of EVM. Despite the recent developments and potential to supersede or provide an alternative to the traditional method, most of the proposed methodologies lack enhanced validation and, thus, have not gained widespread acceptance. For this sole reason, the methodologies chosen to be applied in the EVM Tool are the two that have been validated with large historical datasets, simulation experiments and also withstood the test of time: Earned Value and Earned Schedule.

As per theory, utilization of EVM requires three inputs for each review period in order to determine the corresponding Earned Value (EV):

- Planned Value (PV),
- Actual Costs (AC), and
- Physical progress (% Completion).

In addition to EV, Earned Schedule (ES) can be determined with given input. These three inputs need to be recorded for each review period; PV first prior to start of monitoring, AC and physical progress as the project proceeds. To enable more detailed analysis, the input shall be given for control accounts which in total constitute 100% of the project work and for which the allocation of costs is available. With given input the tool is able to calculate EV and ES (for each review period) for further evaluation of EVM/ES performance measures and forecasts (output).

Calculation of the performance measures and forecasts is very straight forward. Performance measures can be easily calculated with formulas covered in Sections 2.2.2 and 2.3.1, provided input (PV, AC, and physical progress) and determined EV and ES. Similarly the forecasts are computed through provided metrics and performance measures.

4.2.2 Tool Requirements

From product development perspective the issues that initialized the need for EVM implementation need to be converted into requirements. The main problem initially was unreliability in monitoring and forecasting for which the remedy is implementing a consistent practice to monitor and forecast costs. However, discussions with project management personnel have highlighted several needs that should be satisfied by the EVM Tool. The discussed needs have been developed into requirements. The list of requirements is as follows:

1. Excel based
2. Numeric and graphic representation of metrics, performance measures and forecasts available
3. One report view with most relevant performance indicators readily available at one glance
4. Can be used for large projects with several control accounts and review periods
5. Enables consideration of changes in scope
6. Enables adjustment as per project needs
7. Possibility to add new functionalities
8. Visual representation should facilitate readability and highlight the deviations to the baseline performance, and
9. Simple and easy to use interface.

First, the requirements listed can be classified into three categories: *constraints* (1), *functional requirements* (2-7) and *non-functional requirements* (8-9). Further, requirements can be classified as *initial* requirements that have been defined prior to tool development and *ad interim* requirements discovered during the tool development. Last and most importantly, the tool requirements are prioritized into three categories: *critical*, *conditional* and *optional* as per the above assessment of requirements. The product is not acceptable unless critical requirements are being satisfied. Conditional requirements are thought to enhance the product but do not have to be satisfied in order for the product to be acceptable. Optional requirements may or may not be worthwhile. Nonetheless, they do not affect the product acceptance.

First requirement, the constraint to use Excel as a platform, is limiting but also understandable. Excel is a platform that is well known amongst engineers and project personnel, and provides sufficient calculation capabilities and graphics to create a simple tool. Furthermore VBA can be used for programming if more sophisticated solutions are necessary.

Second, the list of functional requirements is more elaborate. The earned value methodology is based on numeric analysis and therefore it is incumbent to provide all of the necessary EVM/ES metrics in numeric form. Also, graphic representations of key metrics can be seen to facilitate intelligibility and trend analysis. However, any kind of a graphic representation does not provide significant additional value and therefore it may be reasonable to consider which metrics need to be represented graphically. It is important to keep the reporting rather simple and not to overwhelm the user with irrelevant visual illustrations to enable effective analysis of provided data. The third requirement is very similar to the second but only defines that such a view shall be available. Understandably, this requirement stems from the need to quickly digest the project status. However, the does not define the “most relevant” performance indicators. Consequently, the relevance of performance indicators shall be weighed on the basis of careful review of related literature.

The fourth requirement demands that the tool shall be capable of handling large projects with several control accounts and review periods. Thus it is left for discretion to define the adequate amount of control accounts and review periods. Given the tendency of changes in projects, the requirement (5) to adapt to scope changes is an integral part of project management and inherently involved in EVM. Also, owing to the unique nature of projects, it is natural to leave some latitude to adjust the tool according to project needs (requirement 6). This kind of requirement can be seen as incomplete since it does not unambiguously explain the dimensions that need to be adjusted. Therefore this could merely be seen as a desire rather than actual requirement and is classified as optional. Further, the development of EVM Tool is seen as an opening rather than a complete solution, so that the tool can be further developed as per user feedback and experience. Thus the requirement of possibility to add new functionalities is of substantial value but not necessary. Fortunately Excel as a platform allows implementation of new functionalities (requirement 7) with rather little expertise.

Two last items of the list are non-functional requirements. In relation to the eighth requirement, indicating the differences to the baseline through various indicators is an integral part of EVM. However, reading the numbers can be exhaustive, and therefore it would be reasonable to guide the user’s attention towards numbers of particular interests, the significant deviations to the baseline, i.e. early warning indicators. After all, EVM is a management-by-exception approach. These two requirements (8 and 9) are here flagged as conditional requirements since fulfilment of the requirement is cannot be clearly defined.

The classification of EVM Tool requirements is summarized in Appendix 1. The classification into initial and ad interim requirements is based on the timing of needs presented. The requirements are seen as ad interim if they are presented after the development of the tool has commenced.

4.2.3 The EVM Tool

Now the EVM Tool has been developed on the basis of given requirements. The tool has been structured to facilitate intelligibility. The tool consists of several tabs of which those requiring user input are highlighted in orange in the tab ribbon. The tabs in the Excel file are as follows: Summary Report, Numeric Report, Graphs, Calculus, Planned Value, % Complete, Actual Cost, Change Management and Settings.

The general layout sets the structure for the tool. In the general layout the time dimension is shown horizontally and the control accounts, metrics, performance measures and forecasts are listed vertically. Representing the time dimension horizontally seems natural since in the context of project management (and also universally) time dimension is generally illustrated as a horizontal dimension. Time is represented horizontally in schedules and Gantt charts beyond exception.

Use of the EVM Tool begins from the Planned Value tab. First, control accounts, corresponding WBS indicators and task (element) names shall be entered on the Planned Value tab and the tool further reflects the provided information on necessary tabs. Setting up control accounts and WBS is part of the planning process and thus Planned Value tab is appropriate site to set up the scope.

As already indicated, EVM requires three inputs for each control account and review period in order to determine the corresponding earned value and earned schedule. These three necessary inputs – planned value (PV), actual costs (AC) and physical progress (% Completion) – are recorded each on their corresponding tabs which are built on a similar template. Screen captures of Planned Value, % Completion and Actual Cost tabs are available in Appendix 2: Figure 2-1, Figure 2-2 and Figure 2-3 respectively. With given input, the tool is able to calculate all EVM/ES based metrics, performance measures and forecasts. The tabs for Planned Value, Actual Costs and Physical Progress are almost identical and do not convey additional information of particular relevance in regards of EVM. The approach to keep the three input feeds separate is thought to reflect the independence of each element of the input triangle.

After a careful review of the theory related to EVM and ES, the tool enables calculation of the necessary metrics, performance measures and forecasts for each control account (CA) and for the total project. The selection is presented in Table 2. In addition to the cost forecasts, corresponding Estimates to Completion are also calculated.

Table 2. EVM/ES metrics provided by the EVM Tool

Description	Cumulative	Periodic	Formula
Metrics			
Earned Value, EV	✓		(1)
Earned Schedule, ES	✓	✓	(16)
Time performance measures based on Earned Value			
Schedule Variance, SV	✓		(2)
Schedule Performance Index, SPI	✓	✓	(3)
Time performance measures based on Earned Schedule			
Schedule Variance, SV(t)	✓		(17)
Schedule Performance Index, SPI(t)	✓	✓	(18)
Cost performance measures			
Cost Variance, CV	✓		(4)
Cost Performance Indicator, CPI	✓	✓	(5)
Cost Forecasts, i.e. Estimate at Completion (€), based on			
Planned performance (PF = 1), $EAC(€)_1$	✓		(23)
Cost Performance Index (PF = CPI), $EAC(€)_2$	✓		(24)
Schedule Performance Index (PF = SPI), $EAC(€)_3$	✓		(25)
Schedule Performance Index (PF = SPI(t)), $EAC(€)_4$	✓		(26)
Schedule Cost Index (PF = SCI), $EAC(€)_5$	✓		(27)
Schedule Cost Index (PF = SCI(t)), $EAC(€)_6$	✓		(28)
Weighed CPI & SPI (PF=0.8×CPI+0.2×SPI), $EAC(€)_7$	✓		(29)
Weighed CPI & SPI(t) (PF=0.8×CPI+0.2×SPI(t)), $EAC(€)_8$	✓		(30)
Time Forecasts, i.e. Estimate at Completion (t)			
Planned performance (PF = 1), $EAC(t)_1$	✓		(32)
Schedule Performance Index (PF = SPI(t)), $EAC(t)_2$	✓		(33)
Schedule Cost Index (PF = SCI(t)), $EAC(t)_3$	✓		(34)
Performance Forecasts, i.e. To-Complete Performance Index			
To-Complete Performance Index, $TCPI_{BAC}$	✓		(13)
Variance Forecasts, i.e. Variance at Completion			
Variance at Completion, VAC_1	✓		(12)
Variance at Completion, VAC_2	✓		(12)
Variance at Completion, VAC_3	✓		(12)
Variance at Completion, VAC_4	✓		(12)
Variance at Completion, VAC_5	✓		(12)
Variance at Completion, VAC_6	✓		(12)
Variance at Completion, VAC_7	✓		(12)
Variance at Completion, VAC_8	✓		(12)

Hence, the tool provides calculation of all metrics, performance measures and forecasts covered in the literature review, save for one. Literature suggests that some of the performance metrics would be more important than others. However, at this point it is not seen necessary to limit the tool drastically and exclude many of the performance metrics provided by the literature. The exception here is the time forecast based on SPI (formula 15) and the reason is twofold. First, the EVM methodology is not a tool for time forecasting, and second, the quirky behavior of SPI can lead to counter-productive overly optimism if one is not aware of it.

In order not to allow the user to damage the calculations, all of the calculus is being performed on Calculus tab which does not necessitate any user input and is further reflected on other tabs where necessary. All of the calculated values are comprehensively presented on the Numeric Report tab. A screen capture of Numeric Report tab is provided in Appendix 2, Figure 2-4.

All of the produced graphs are presented on the Graphs tab. The selection of graphs is based on three criteria. Graphical representation is included if it:

1) Provides additional value
2) Facilitates understanding of the bigger picture, or
3) Facilitates understanding of trends in performance.

Hence, the following six graphs for the total project are being produced:

- The traditional EVM S-curve (Appendix 3, Figure 3-1)
- Earned Schedule graph (Appendix 3, Figure 3-2)
- Cumulative Performance Measure graph (Appendix 3, Figure 3-3)
- Periodic Performance Measure graph (Appendix 3, Figure 3-4)
- Cumulative Performance Variance graph (Appendix 3, Figure 3-5), and
- Cost Forecast graph (Appendix 3, Figure 3-6).

The time dimension, plotting the review periods, is naturally presented on the horizontal axis in all of the graphs.

The first two diagrams represent the EVM/ES metrics and allow straightforward comparison of baseline and actual performance. The traditional EVM S-curve represents the Planned Value, Earned Value and Actual Costs on the vertical axis in form of a line chart. The budget (i.e. total Planned Value) is indicated as a horizontal dashed line and current review period (actual time) as vertical line. The ES diagram is as well a line chart where vertical axis represents time (i.e. review periods), ES is drawn as per progress and baseline is illustrated as a dashed straight line. These types of generic diagrams are considered effective for providing a quick look at the overall performance of the project.

The performance measure diagrams allow more detailed monitoring of the three project performance measures: CPI, SPI and SPI(t). The cumulative diagram allows monitoring of overall performance trends whereas the periodic diagram enables more accurate analysis of short-term tendencies. As per theory value of 1 corresponding to 100% baseline equivalence represents perfect baseline performance. Higher values indicate performance over the baseline and lower values underperformance.

The performance variance diagrams detail the trends of the three performance variances: CV, SV and SV(t). As opposed to the performance measure diagrams, the performance variance diagram represents differences to the baseline in terms of absolute values. Since action thresholds can be provided in relative or absolute terms, representation of both relative and absolute trends is considered to provide additional value.

Last, the Cost Forecast diagram is a graphic illustration of selected cost forecasts. The three selected forecast lines are the highest forecast ($EAC(€)_{max}$, higher boundary), lowest forecast ($EAC(€)_{min}$, lower boundary) and one user defined forecast. The user defined forecast can be any of the eight presented forecasts and is selected from a drag-down menu next to the graph. The forecast lines represent the actual costs until current review period. Thereafter the lines are calculated as linear extrapolations leading to the forecasted value final. That is, the lines do not account for the shape of planned accrue of progress but are only linear representations.

The amount of forecasts in the graph is limited for two reasons. First, the objective of forecasting is to see where the project is headed. Since probability of each forecast is unknown, it does not make sense to structure the graph as a distribution of several forecasts. Second, plotting all of the forecasts would drastically decrease the readability of the graph.

The selection of the three forecasts has been performed on the basis of two fundamental aspects regarding EVM forecasting. First, EVM is fundamentally a management by exception approach. The most significant deviations to the baseline are most likely to provide an early warning and to cross the set action thresholds. Moreover, the extremities also form an event space where the project is likely to be headed. Second, selecting a forecast is always subject to project manager's expert judgment. In combination, the user can easily analyze how the selected forecast relates to the expected range of possibilities.

Another option to include all of the forecasts would have been to create a distinct graph for each of the forecasts. However, it is considered easier and of lesser effort to select the forecast from the drag-down menu next to the graph than scrolling up or down to find the forecast of interest from the tab.

A graph for time forecast is not presented since the graphic illustration is not considered to provide particular additional value in addition to the numeric format.

The report view, i.e. the Summary Report tab, provides a joint representation of key performance information. This view includes the traditional EVM S-curve and selection of key metrics based on latest inputs. The selection of metrics is presented in Table 3. A screen capture of Summary Report tab is available in Appendix 2, Figure 2-5.

In addition to EVM/ES metrics, the total budgeted cost (TBC), review period (i.e. actual time AT) and planned duration (PD) have been provided as general information.

The selection has been performed based on a careful review of related literature. The objective was to provide a comprehensive joint set of earned value data. The selection criteria are as follows:

- The foundation of performance metrics shall be covered
- Both cost and time dimensions need to be present
- Selected metrics shall cover overall (including past), current and future dimensions
- Both absolute and relative deviations to the baseline shall be covered (if readily available)
- The selection shall provide answers to the common project management questions presented in Section 2.1.1.

Table 3. Selection of EVM/ES metrics, performance measures and forecasts in Summary Report tab

Description	Cumulative	Periodic	Formula	Question
Metrics				
Planned Value, PV	✓		Input	-
Actual Cost, AC	✓		Input	-
Earned Value, EV	✓		(1)	-
Earned Schedule, ES	✓		(16)	-
Time performance measures based on Earned Schedule				
Schedule Variance, SV(t)	✓		(17)	1
Schedule Performance Index, SPI(t)	✓	✓	(18)	2
Cost performance measures				
Cost Variance, CV	✓		(4)	4
Cost Performance Indicator, CPI	✓	✓	(5)	5
Cost Forecasts, i.e. Estimate at Completion (€) based on user selection				
Estimate at Completion, $EAC(€)_x$	✓		(23)	8
To-Complete Forecasts, i.e. Estimate to Completion (€) based on user selection				
Estimate to Complete, $ETC(€)_x$	✓		$EAC(€)_x$ - AC	7
Variance Forecasts, i.e. Variance at Completion (€)based on user selection				
Variance at Completion, $VAC(€)_x$	✓		(12)	9
Time Forecasts, i.e. Estimate at Completion (t) based on user selection				
Selected Time Forecast, $EAC(t)_x$	✓		(32)	3
Performance Forecasts, i.e. To-Complete Performance Index				
To-Complete Performance Index, $TCPI_{BAC}$	✓		(13)	6

Considering the criteria above, the only metrics excluded are the traditional time performance metrics, schedule performance index (SPI) and schedule variance (SV), most of the time forecasts (EAC(t)), cost forecasts (EAC(€)) and corresponding to-complete forecasts ETC(€) and variations at completion (VAC). However, they are excluded for a reason.

In the current selection, the time performance is expressed by ES time performance measures. ES time performance measures are preferred for two reasons indicated by Lipke (2003), that is, the quirky behavior of SPI towards seemingly perfect performance and the false impression that the time performance metrics can be used for cost performance reporting. Consequently, the ES time performance metrics are considered more reliable and, have actually shown to outperform the traditional EVM counterparts in duration forecasting.

The selection of key metrics includes only one cost and one time forecast. That is, seven cost forecasts (and corresponding ETC's and VAC's) and two time forecasts are not shown in the report view which might seem rather limiting. Any given forecast can be correct for any given project and provide an early warning indication for the project management. The best forecast in each situation depends on the project and the prevailing circumstances. Ultimately, the choice of appropriate forecast is subject to project manager's preference and is therefore left for the user. It is, however, important that the project manager acquaints oneself with EVM methodology and is equal to the occasion. If it is seen best to be grounded on related studies, the traditional EAC(€)$_1$ has been shown the most stable and weighted CPI and SPI(t) based EAC(€)$_8$ most accurate. Comparable results for given time forecasts could not be identified and, thus, all three alternatives are seen equal.

It is also important to acknowledge that EVM itself is not a tool for forecasting. Rather, in addition to the performance measures, the forecasts are used to indicate deviations to the baseline. Therefore particular emphasis should not be placed on forecast readings but the deviations to the baseline should be considered as indications to take corrective actions, if necessary.

EVM is a management-by-exception approach. Therefore, the selected key metrics are equipped with traffic lights which are added to arrest the user's attention towards metrics that show user defined deviations to the baseline. The red, yellow and green traffic lights illustrate user defined poor, average and good performance, respectively.

The Settings tab is created to allow for user preferences and project specific tailoring. For the time being the traffic lights are limited to key metrics shown on the Summary Report tab. The tab includes options which allow the user to modify the tripartite traffic lights illustrated besides the key metrics. More specifically, the user can determine two boundary values that determine the three traffic light illustrations to enable to effortlessly notice the exceeding of predefined deviations. The traffic lights can be set to act as (project specific) early warning indicators. Hence, the effect of settings is purely visual and does not influence the calculations whatsoever. Owing to unique nature and diverse objectives of projects, the selection of thresholds is left for the user. However, guidelines for setting the appropriate thresholds are provided in Section 4.1.4. A screen capture of the Settings is available in Figure 16. The user definable cells have been indicated with gray background: selection of forecasts on the left and adjustment of thresholds on the right.

The Change Management tab is used for managing changes to the baseline plan. Initially Change Management tab reflects the baseline data from Planned Value tab. However, if a change in the baseline occurs, the reflected Planned Value data in the Change Management tab shall be overwritten with updated baseline data which then further reflects the updated baseline in the tabs and calculations necessary. A screen capture of Change Management tab is provided in Appendix 2, Figure 2-6.

Since current and future works cannot be performed in past, the Change Management tab possesses a characteristic which highlights the past periods in red color for the user to identify where the budgets can and cannot be moved in the updated plan. Naturally the incomplete work shall be moved from the past to future but not the other way around. The highlight functionality is automatically governed by the input sets of the user: % complete and actual costs. If data has been recorded for either of the two sets for a certain period of time, the formula counts for it and highlights the respective period in Change Management tab. However, the Change Management, as a functionality, possesses certain limitations. Naturally each change requires two sets of details: the baseline and the revised baseline. Now that the tool includes only two databases, it allows only one baseline change during the project. If another baseline change is being done afterwards, the data for the period between the baseline changes may be incomplete depending on the changes made. Hence it is true that the change management is functional but fully functional only to the extent of one baseline change.

Project:	*Sample Project*			
		Acceptance limits		
	Bad	**Average**	**Good**	
Cost performance				
CPI		0,85	0,95	
CV		-15 %	-5 %	% ± Budget at Completion
		-2 914 471,58 €	*-971 490,53 €*	
Time performance				
SPI(t)		0,85	0,95	
SV(t)		-15 %	-5 %	% ± Planned Duration
		-2,85	*-0,95*	
Periodic performance				
CPI_{per}		0,85	0,95	
$SPI(t)_{per}$		0,85	0,95	
Performance to Complete				
TCPI		1,05	1,1	
Selected COST Estimate at Completion				
Estimate at Completion (EAC2(€))		15 %	5 %	% ± Budget at Completion
		22 344 282,09 €	*20 401 301,04 €*	
		-2 914 471,58 €	*-971 490,53 €*	
Selected TIME Estimate at Completion				
Estimate at Completion (EAC1(t))		15 %	5 %	% ± Planned Duration
		21,85	*19,95*	

Figure 16. Screen capture of Settings tab in the EVM Tool

5 Analysis and Discussion

The intent of this thesis was to provide comprehensive understanding of Earned Value Management methodology and create a tool to practice EVM which allows better monitoring and control of project costs. It included a review of related literature, state-of-the-art, useful guidelines in practicing EVM and assessing the current status of Caverion Industria Project Services in order to enable proper cost monitoring and control of projects with Earned Value Management. All of these goals were accomplished – with certain limitations.

A careful review of related literature paved the path for development of an EVM Tool. The Excel-based tool is founded on methodologies which can be considered the best validated industry practices available: Earned Value Management and Earned Schedule. The tool is not only designed to provide a comprehensive but concise review of current status but also to allow more profound analysis of EVM/ES metrics and forecasts with required input.

In the objectives of the work, there was no reference to implementation of EVM as part project management process. Nevertheless, one of the most essential realizations was that Earned Value Management does not function without the supporting project management processes. The rubric of Fleming and Koppelman in Section 2.5 Earned Value Management Implementation thoroughly sets out the steps and processes necessary to enable proper implementation of the methodology. Therefore it was incumbent to decipher the rubric and assess the current status of CaIn PS to enable introduction of the methodology and utilization of produced EVM Tool.

One major consideration in relation to the scope of this work and, thus, results is lack of validation. The methodology has not yet been implemented and the tool has not been subject to empirical testing. Validation was left out of scope owing to lack of resources. However in the retrospect, it would have been material to include the validation in the scope of work. Nevertheless, the capabilities of the tool have been analyzed in respect to tool requirements and needs of CaIn PS in implementing the Earned Value methodology.

Analysis and suggestions in relation to EVM implementation process as well as created tool will be discussed in the following.

5.1 Selection of Methodologies and Extensions

As already indicated in Section 2.3, a lot of research effort has focused on developing more accurate methods for performing cost control by extending the theoretical basis of EVM. Especially Earned Duration Management and Schedule Adherence concept have shown notable potential to extend the theoretical basis of EVM and provide additional value, especially in regards of the time dimension.

EDM seems rather similar to EVM and ES, and therefore its implementation to the existing EVM tool should not require considerable effort. The framework for Schedule Adherence concept on the other hand is more extensive and its implementation to the existing framework would require considerable efforts. However, the basis of the approach rather seems convincing, especially in context of industrial construction. Rework and impediments, causing inefficient performance e.g. due to shift of resources from constrained activities, are fairly common issues in industrial construction since planning and design are usually not complete at the time of construction. Since these aspects are not considered in EVM and ES, the concept could indeed provide additional value not only in regards of performance measurement and forecasting but also in convincing other stakeholders of the consequences of impediments and rework in construction. Therefore, it is suggested that these methodologies could be further studied in the future, and when and if significant proof of their benefits is substantiated, these methodologies could be implemented to complement the existing EVM/ES framework in performance measurement and forecasting.

Regarding forecasting it was stated that the choice of appropriate forecast is ultimately left for the project manager. In this regard, assessment of forecast quality could help the project manager in selecting the appropriate forecast for each situation. Assessment of forecast stability could be easily implemented in the existing Excel framework but assessment of forecast accuracy on the other hand would require Monte Carlo simulation which is not an asset that is available to Caverion Industria for the time being. Owing to this shortcoming, and that these aspects are considered equally important dimensions of forecast quality, it was seen appropriate not to implement a partial assessment of forecast quality in the EVM Tool. However, when and if Monte Carlo simulation is an asset that is available, it is suggested that the forecast quality is being assessed to assist the project manager in selecting the forecast.

5.2 Implementation and Operation Retrospect

The implementation of EVM methodology may call for changes in operating practices as also indicated by Webb (2003, p. 7) in his book *Using Earned Value: A Project Manager's Guide*. He further elaborates that such changes could include but are not limited to greater discipline in planning processes, greater emphasis on objective reporting, improved integration between the planning systems and the accounting systems, and even implementation of a new software. In assessing the current situation at CaIn PS and reforms of the near future, it can be noticed that the potential changes mentioned by Webb are at the moment on-going or to be implemented in CaIn PS:

- The control team is being introduced to deal with greater discipline in planning processes.
- EVM methodology inherently demands to emphasize on objective progress measurement to allow accurate performance measurement.
- The soon-to-be introduced SAP PS is considered to allow better integration capabilities than the previous V10.
- The EVM Tool has now been developed to assist the control and the project teams in practicing EVM.

Hence, it could be concluded that CaIn PS is already taking meaningful steps towards higher project management maturity but a lot of work is still ahead in order to master EVM in practice.

One of the objectives of this work was to provide assistance in implementing the EVM methodology to support cost management. Indeed, EVM is a tool to assist in cost management. However, in the context of project management, cost management is fairly integrated to other process and implementation of EVM requires application of good project management principles to be used effectively. This realization was probably the most impactful regarding the content of this study and one of the two major final outcomes which is the EVM implementation rubric. When implementing such an integrative methodology, the bigger picture must also be considered.

The presented EVM implementation rubric is rather general but covers quite comprehensively the project management principles and practices that are necessary to enable proper application of EVM. There are various tools, techniques and practices available to assist in each step of the rubric and some strategic decisions may have to be made in course of the implementation. The EVM implementation rubric, however, provides a robust framework to build upon.

First, one of the most important steps in employing EVM is defining the scope of work (step 1 in the rubric). As has been described in Section 2.4.2, one of the most useful tools for any project manager, and undisputable cornerstones in integrating the project management triangle, is the work breakdown structure. For the meantime developing a WBS has not been an exercise that is being practiced consistently. However, this is to be changed as CaIn PS is now about to implement EVM methodology as is demanded by the implementation rubric.

In general terms, the scope definition by means of a WBS provides a framework to for proper integration of the three fundamental aspects of project management: scope, schedule and cost. Therefore cost accounting and scheduling should also be based on the project specific WBS. Now in order to assist creating WBSs', facilitate cost accounting and to reduce unnecessary work, it is suggested that a WBS template would be produced that reflects the more common elements of the scope of work in most of the projects being executed. Ideally, the WBS template would be rather extensive so that the amount of elements that need to be added would be minimal. A proper WBS template would provide a proper basis for future planning processes, guide the project team in defining the scope appropriately and reduce the work related to defining the scope. More importantly, SAP PS also features the possibility to incorporate a WBS. Hence, the template could be incorporated in SAP PS to facilitate allocation of costs and potentially part of the cost allocation could be automatically allocated which would effectively reduce the manual work which is to be performed by project controllers and financial administration.

In the context of the first step in the implementation rubric, an appropriate size for work packages (40-80h) and 100-0 measurement approach were suggested. These suggestions were selected from a variety of different opinions discovered in the literature review. It is however true that the appropriate size of work packages and measurement approach are subject to characteristics of the project work. Therefore these should not be considered as strict guidelines that must be adhered to but rather go-to options that should be primarily considered. For example there may be occasions where it does not make sense to decompose all of the work packages to this level. In such occasions the percent completion estimate with milestone gates could be a reasonable approach for measurement as already indicated in the context of step 5.

One of the conclusions in relation to step 3 is that the planning efforts should commence already in the tender phase. While it is true that complete set of details in regards of the project may not be available already in tender phase, it would be helpful for two reasons. First, setting up the plan would support the tendering process in estimating the resources and assessing the achievability of timely delivery of project deliverables. Second, if the timely delivery is deemed achievable, having a comprehensive plan in the tender phase would also support in achieving the contract award by increasing the stakeholder and customer confidence in achieving the deliverables. Naturally commencement of planning activities in tender phase could be considered too big of a burden for smaller size projects and then it could be postponed to time after contract award. Surely having an initial plan in tendering phase would also help in attracting binding offers from subcontractors which would facilitate in determining who will perform the work and making make-or-buy decisions (step 2).

Practicing EVM also requires greater discipline in planning processes. The control team has quite recently been established and the processes need to be further developed to support the EVM practice. Especially regarding step 3, the processes for scheduling and forecasting need to be further developed and appropriate techniques selected to establish a solid foundation for future planning and control operations.

In relation to items 4, 8 and 10 in the implementation rubric, there seems to be contradicting opinions regarding the definition of performance measurement baseline. The bone of contention here is the contingency reserve, i.e. undistributed budget for known unknowns or identified risks, and whether it should be included in the initial performance measurement baseline or not. Thinking from a wider perspective, there appears to be reasonable motives for both of these views. Therefore in the implementation rubric it has been advised that inclusion of contingency reserves in the performance measurement baseline is a choice for the project manager.

If one is to use realistic estimates in estimating the resources and authorizing budgets, it makes perfectly sense not to incorporate contingency reserves in the performance measurement baseline but to allocate the contingencies in the change management process as per materialized risks as is suggested by Lukas (2008). However, considering reporting to higher management, customers and other stakeholders, which are likely to care more about the money actually budgeted for the project and project funding requirements, it would be reasonable to incorporate the contingency reserves into the performance measurement baseline. A conscious project manager may even want to see both types of baselines to take advantage of both approaches. Although the decision is now left subject to project manager's preference, it may well be a strategic decision which is to be taken by the control team and management in order to avoid confusion and commit to only one organization wide practice.

Step 6 in the EVM implementation rubric describes the determination of control account plans i.e. CAPs which are selected management control points in the WBS where the measurement of performance will take place. This instruction sets out the requirements for CAPs but the determination is left for the project manager. Each project is different and therefore one may not be able to definitely define the placement of CAPs in the WBS without necessary project details. The CAPs need to be carefully determined to support the EVM performance measurement in the most meaningful way. Especially if a WBS template is being established, the placement of CAPs needs to be extensively analyzed to be fitting for a variety of different projects.

Recording and allocating of costs may prove to be one of the more difficult tasks regarding the EVM practice. Producing reliable data from the cost accounting systems for EVM purposes should not be of problem but the challenge resides in the adjusted actuals. As described, the adjusted actuals should be based on reliable monitoring of working hours, meaning all project related work should be tracked by a working time tracking system, namely Jotbar. This is not a problem in the back office but can prove to be challenging where most of the actual deliverables are being produced: at the construction site. The challenge in tracking the working time accurately is threefold.

For the time being Jotbar working time tracking system is being used occasionally. The first challenge is to make it an organization wide practice. Second, the tracking system should also be available at construction sites, preferable close to where the work is being performed. It is rather common to locate the Jotbar terminals at the access points. However, this may not serve the purpose on larger construction sites where the work can be up to one or two kilometers away from the nearest access point. Hence, changing the task to another would mean considerable amount of idle time which does not produce value in regards of the actual work and would yield in additional costs. Also setting up internet connection for the terminal in the middle of construction site may be challenging. The third challenge is to make the workers aware of the elements of work they are performing so that they are able to record the hours properly. The workers need to be educated to act accordingly. Therefore the practice in monitoring the working time according to the WBS will be a challenge that needs to be tackled in order to yield reliable data for performance measurement purposes.

Sections 4.1.3 and 4.1.4 complete the study by describing how to perform earned value analysis and how to interpret the produced data. The management approach is being characterized, the supporting analysis techniques and their intents are being described, and finally the common implications of more important performance indications are being deciphered. As more experience of EVM practice is being gained and EVM data is being gathered, it may be useful to analyze the company dataset to build up a better understanding of company and work specific impulses and exploit this information in determining appropriate thresholds and interpreting tendencies.

In conclusion, the implementation rubric provides a comprehensive guideline for implementing the EVM methodology and performing earned value analysis. Some of the implementation instructions are presented in a rather high level which leaves room for selecting the most suitable tools and techniques for future practice. Considering the urge to further develop project maturity, these instructions and observations provide a solid basis to practice EVM and potentially to develop an organization wide guideline for practicing EVM in Caverion Industria Project Services.

5.3 EVM Tool – A Vehicle, Not a Final Product

The second primary objective of this work was to develop an Excel based EVM Tool to assist in practicing EVM. The tool has now been developed according to requirements set in the results. However, and very importantly, the tool has not been yet been tested. Therefore it is incumbent to test that the tool works as expected by the methodologies behind it. If the tool does not function as is expected, it could result in severe problems. Especially if it does not yield reliable early warning indicators as it should, it could result in false sense of well-being, corrective measures are not taken and projects may not be able to deliver the project deliverables in time. In the worst case this would yield in severe economic losses. Therefore, as a future work, a comprehensive test plan needs to be developed and appropriate measures taken to validate the functionality of the tool.

Now evaluating the EVM Tool in light of the predefined requirements, it seems to satisfy all of them, however, with certain limitations. To begin with, the tool is Excel based as required (1) which also inherently enables addition of new functionalities (7). Regarding further development of the tool, Excel provides sufficient capabilities to modify and extend the framework especially if the selection of tools is extended from exploiting only formulas to the diverse possibilities provided by Visual Basic programming integrated in the Excel framework. However, for the time being the EVM Tool is based on formulas which seem to fulfil the requirements of the tool with certain limitations which will be discussed in pursuance of the following requirements assessment. The remaining requirements will be talked through in the following.

The tool enables numeric and graphic representation of metrics, performance measures and forecasts as is required by the requirements list (item 2). These features are certainly the key assets that enable variance analysis, trend analysis and eventually noticing the exceeding of predefined deviations to the baseline (i.e. early warning indicators) which is inherently demanded by the methodology. Moreover, it is supported by a feature that highlights these occurrences which facilitates the user in detecting these anomalies in performance (requirement 8). It is however disputable whether the provided graphs are sufficient to satisfy the needs for trend analysis but in light of the reviewed literature the provided selection of graphs for the total project seems to be satisfactory. However, one may consider whether similar graphs for control accounts would be useful. Hence, in case the current selection is found inadequate, further graphs can be easily produced on the basis of extensive numeric data provided by the EVM Tool.

In relation to third requirement, the EVM Tool provides a report view with the most relevant performance indicators readily available at one glance. This Summary Report tab is designed to provide a concise view of the project status and to satisfy the reporting needs to higher management. However, the management may not be equally capable to interpret the provided EVM/ES data. Therefore the numbers and graphs would potentially need to be complemented with textual interpretations and explanations for the management to have better understanding of the status. Hence, as a future prospect, it could be necessary to structure the report view in a more meaningful way according to provided feedback.

Moving forward to fourth requirement, the EVM Tool can be used for large projects with several control accounts and review periods. The number of control accounts and review periods is limited but easily scalable. The formulas can be further copied in case more extensive framework is required. Excel naturally has it limits in the number of columns and rows it can process but these limits are far beyond the needs that are foreseen for larger future projects.

The fifth requirement stipulates that the EVM Tool must enable consideration of changes in scope. This is one of the five critical requirements in the requirements list. While it is true that the product enables changes in the scope of work, this feature comes with certain limitations and needs to be clarified. The change management is built upon two sets of data: the baseline plan (Planned Value tab) and the updated baseline (Change Management tab). Since there is no possibility to save more than two sets of data in the current product, it means that the scope change feature allows without additional user effort only for one set of changes in scope. The possibility to have several updates to the original plan would require full details of each update to the plan. However, there is one partial workaround for this. Now that the contents of the product are not protected, the user can freeze the calculated values for past review periods in the Calculus tab for the total project values by copy/pasting the values onto the formulas. This will allow having the correct data for past review periods available for the total project. However, the complete set of data (metrics, performance measures and forecasts) is not coexistently available since the data for control accounts is calculated for one control account at a time. Therefore depending on the changes made, there could be some bouncing of control account specific data in-between the two review periods between which the change in plan has been made. Another way to deal this complete would be to issue a new file for each baseline update when there would always be the complete set of data available. However, this would mean that the user would have to switch between the files according to the review periods of interest which would evidently complicate understanding the full picture and longer term trends.

One may of course consider whether occurrence of two or more baseline changes during a project is common or not. In an ideal project baseline changes would not be necessary. Everything would go as planned and there would be no need to touch the baseline. However, not many projects, if any, go perfectly as planned. Moreover, changes in scope or schedule are rather common in industrial construction. Therefore it is deemed that limitation to one baseline change does not fulfil the requirement for most of the projects. The current product does not completely fulfil the fifth requirement and needs to be improved. Hence, in the future, the change management feature needs to be structured in a way that it is able to capture complete datasets for every change and thus allows making changes to the baseline without limitations.

The EVM Tool provides a set of options to adjust the thresholds for highlighted deviations to the baseline as per project needs (requirement 6). Fulfilment of requirement 6 was considered optional owing to its ambiguity. However, it can be helpful for an experienced user to define the thresholds in a way that better suits for the nature of the project. For example too narrow thresholds may disturb with false alarms and project team's valuable time will be lost for unnecessary performance analysis which could be used for actual work. The set of options covers the more important performance indicators and selected forecasts which is deemed to be sufficient.

The two last items (8 and 9) in the requirements list were defined as non-functional conditional requirements. This means that the requirements would enhance the product but the product is not unacceptable if they are absent. In development of the product these aspects (visual representation should facilitate readability and highlight the deviations to the baseline performance, simple and easy to use interface) have been considered and realized to good effect. However, the usability shall be considered as per user feedback in future development of the product.

Further regarding functionality of the EVM Tool, during the tool development several useful features that would complement the tool have been discovered. Notably these additional features are not in the scope of this study but could be considered future work that could improve the tool and facilitate future EVM practice. These helpful features are discussed in the following.

First, the developed EVM tool is designed to work on control account level for which the cost allocation should as a bare minimum be performed. However, in spite of Vanhoucke and Vandevoorde (2007) conclusion that performance measurement on higher levels (i.e. control account level) is the only applicable approach for practitioners, it would be beneficial to also have visibility on the performance in lower levels of WBS. This holds true especially if the underlying causes of higher level trends need to be drilled down to lower levels to further analyze the underlying causes of the higher level performance. Therefore it would be useful to structure the EVM Tool in a way that it could also process the lower level elements. Ideally the tool could enable processing of EVM features for the total WBS in its vast entirety and also perform the summation of lowest level WBS elements to the top. Hence, it is suggested to further investigate implementation of this feature in future development of the EVM Tool.

Another aspect that needs to be considered is automation of the data input process which also relates in particular to items 7 and 8 in the implementation rubric. At the moment all of the necessary inputs need to be recorded manually, one by one, which means considerable amount of manual work in setting up the plan and changes, and especially in updating the progress and costs for each review period. Thus it could be useful to develop an interface that would minimize the manual efforts. The cost data is evidently available from SAP and the progress data (% completion) from MS Project. Both of these systems allow the user to capture the data in a predefined format. On this basis, it would be possible to develop a structure in the EVM Tool where the data could be pasted and the EVM Tool would then further collect the required information in respective databases. This would effectively reduce the work necessary in updating the values and increase the timeliness of performance measurement and forecasting.

One important user-friendliness and functionality related aspect of the EVM Tool is protection of critical content. In relation to the requirements, this would partially fall under the conditional requirement number 9: simple and easy to use interface. At the moment this is not a feature incorporated in the product that will most likely be under serious development activities in the near future. However, this would certainly be a feature that will be included in the final version of the EVM Tool that will be published for use.

Overall the EVM tool fulfils the set requirements, save for some limitations. For the time being the EVM Tool should not be considered as a final product but rather a vehicle that is under constant development until the right workings and functionalities have been discovered and the tool has undergone a serious set testing. Only thereafter can the product be used to support the EVM practice.

6 References

Acebes, F., Pajares, J., Galán, J.M. and López-Paredes, A., 2013. Beyond earned value management: A graphical framework for integrated cost, schedule and risk monitoring. *Procedia-Social and Behavioral Sciences,* **74**, pp. 181-189.

Allen, W., 1979. *Developing the project plan*. Notes prepared for Engineering Institute of Canada Annual Congress Workshop, Toronto, pp. 3-9.

Anbari, F.T., 2003. Earned value project management method and extensions. *Project Management Journal,* **34**(4), pp. 12-23.

Association for Project Management, 2013. *Earned Value Management Handbook*. [PDF] Available at: https://www.apm.org.uk/sites/default/files/earned%20value%20management%20handbook_secure.pdf.

Atkinson, R., 1999. Project management: cost, time and quality, two best guesses and a phenomenon, it's time to accept other success criteria. *International Journal of Project Management*, **17**(6), pp. 337-342.

Baloi, D. and Price, A.D., 2003. Modelling global risk factors affecting construction cost performance. *International Journal of Project Management,* **21**(4), pp. 261-269.

Barraza, G.A., Back, W.E. and Mata, F., 2004. Probabilistic forecasting of project performance using stochastic S curves. *Journal of Construction Engineering and Management,* **130**(1), pp. 25-32.

Barraza, G.A., Back, W.E. and Mata, F., 2000. Probabilistic monitoring of project performance using SS-curves. *Journal of Construction Engineering and Management,* **126**(2), pp. 142-148.

Barraza, G.A. and Bueno, R.A., 2007. Probabilistic control of project performance using control limit curves. *Journal of Construction Engineering and Management,* **133**(12), pp. 957-965.

Batselier, J. and Vanhoucke, M., 2015. Evaluation of deterministic state-of-the-art forecasting approaches for project duration based on earned value management. *International Journal of Project Management,* **33**(7), pp. 1588-1596.

Brotherton, S.A., Fried, R.T. and Norman, E.S., 2008. Applying the work breakdown structure to the project management lifecycle, *PMI Global Congress Proceedings* 2008, pp. 1-15.

Caron, F., Ruggeri, F. and Merli, A., 2013. A Bayesian approach to improve estimate at completion in earned value management. *Project Management Journal,* **44**(1), pp. 3-16.

Carroll, J., 2017. Earned Value Management in easy steps: *Keep tabs on the status of all projects, including agile projects*. [e-book]. In Easy Steps Limited. Available at: https://books.google.fi/books?isbn=1840787805.

Chang, A.S., 2001. Defining cost/schedule performance indices and their ranges for design projects. *Journal of Management in Engineering,* **17**(2), pp. 122-130.

Chen, H.L., Chen, W.T. and Lin, Y.L., 2016. Earned value project management: Improving the predictive power of planned value. *International Journal of Project Management,* **34**(1), pp. 22-29.

Chen, S. and Zhang, X., 2012. An analytic review of earned value management studies in the construction industry, *Construction Research Congress 2012: Construction Challenges in a Flat World* 2012, pp. 236-246.

Christensen, D.S., 1998. The costs and benefits of the earned value management process. *Journal of Parametrics,* **18**(2), pp. 1-16.

Christensen, D.S., Antolini, R.C. and McKinney, J.W., 1992. A review of estimate at completion research. *Cost estimating and analysis.* Springer, pp. 207-224

Cioffi, D.F., 2005. A tool for managing projects: an analytic parameterization of the S-curve. *International Journal of Project Management,* **23**(3), pp. 215-222.

Colin, J. and Vanhoucke, M., 2015. A comparison of the performance of various project control methods using earned value management systems. *Expert Systems with Applications,* **42**(6), pp. 3159-3175.

Covach, J., Haydon, J.J. and Reither, R.O., 1981. *A study to determine indicators and methods to compute estimate at completion (EAC).* Virginia: ManTech International Corporation.

Czarnigowska, A., Jaskowski, P. and Biruk, S., 2011. Project performance reporting and prediction: extensions of Earned value management. International Journal of Business and Management Studies, 1, pp. 11-20.

Czarnigowska, A., 2008. Earned value method as a tool for project control. *Budownictwo i Architektura,* **3**, pp. 15-32.

Czemplik, A., 2014. Application of earned value method to progress control of construction projects. *Procedia Engineering,* **91**, pp. 424-428.

De Marco, A., Briccarello, D. and Rafele, C., 2009. Cost and schedule monitoring of industrial building projects: Case study. *Journal of Construction Engineering and Management,* **135**(9), pp. 853-862.

De Marco, A. and Narbaev, T., 2013. Earned value-based performance monitoring of facility construction projects. *Journal of Facilities Management,* **11**(1), pp. 69-80.

Devi, T.R. and Reddy, V.S., 2012. Work breakdown structure of the project. *International Journal of Engineering Research and Applications,* **2**(2), pp. 683-686.

Fleming, Q.W., 1992. *Cost/schedule Control Systems Criteria: The Management Guide to C/SCSC.* 2nd ed. Chicago, Illinois: Probus Publishing Company.

Fleming, Q.W and Koppelman J.M., 2010. *Earned Value Project Management*. 4th ed. Newtown Square (PA): Project Management Institute.

Fleming, Q.W. and Koppelman, J.M., 2009. The two most useful earned value metrics: the CPI and the TCPI. *Cost Engineering,* **51**(3), pp. 16-18.

Fleming, Q.W. and Koppelman, J.M., 2007. Implementing Earned-Value Project Management in Ten Easy Steps. *Field Guide to Project Management, Second Edition,* pp. 521-539.

Fleming, Q.W. and Koppelman, J.M., 2006. Start with "Simple" Earned Value on all your projects. *CrossTalk The Journal of Defense Software Engineering,* pp. 9-14.

Gershon, M., 2013. Using earned value analysis to manage projects. *The Journal of Applied Business and Economics,* **15**(1), pp. 11-14.

Grisham, T.W., 2010. *International project management: Leadership in complex environments.* John Wiley & Sons.

Haugan, G.T., 2002. *Effective work breakdown structures.* Management Concepts Inc.

Hazir, Ö., 2015. A review of analytical models, approaches and decision support tools in project monitoring and control. *International Journal of Project Management,* **33**(4), pp. 808-815.

Henderson, K., 2004. Further developments in earned schedule. *The measurable news,* **1**(1), pp. 15-22.

Henderson, K. and Lipke, W., 2006. Earned schedule: An emerging enhancement to earned value management. *Cross Talk, Journal of Defense Software Engineering*, **November**, pp. 26-30.

Henderson, K. and Zwikael, O., 2008. Does Project Performance Stability Exist? A Re-examination of CPI and Evaluation of SPI (t) Stability. *Crosstalk, The Journal of Defense Software Engineering*, **April**, pp. 7-13.

Jacob, D., 2003. Forecasting project schedule completion with earned value metrics. *The Measurable News,* **1**(11), pp. 7-9.

Jacob, D.S., and Kane, M., 2004. Forecasting schedule completion using earned value metrics revisited. *The Measurable News*, **Summer**, pp. 11-17.

Jung, Y., 2005. Integrated cost and schedule control: Variables for theory and implementation, *Construction Research Congress 2005: Broadening Perspectives* 2005, pp. 1-10.

Kerkhove, L. and Vanhoucke, M., 2017. Extensions of earned value management: Using the earned incentive metric to improve signal quality. *International Journal of Project Management,* **35**(2), pp. 148-168.

Khamooshi, H. and Abdi, A., 2016. Project duration forecasting using earned duration management with exponential smoothing techniques. *Journal of Management in Engineering,* **33**(1), pp. 04016032.

Khamooshi, H. and Golafshani, H., 2014. EDM: Earned Duration Management, a new approach to schedule performance management and measurement. *International Journal of Project Management,* **32**(6), pp. 1019-1041.

Kim, B., 2014. Dynamic control thresholds for consistent earned value analysis and reliable early warning. *Journal of Management in Engineering,* **31**(5), pp. 04014077.

Kim, B. and Kim, H., 2014. Sensitivity of earned value schedule forecasting to S-curve patterns. *Journal of Construction Engineering and Management,* **140**(7), pp. 04014023.

Kim, B. and Reinschmidt, K.F., 2011. Combination of project cost forecasts in earned value management. *Journal of Construction Engineering and Management,* **137**(11), pp. 958-966.

Kim, B. and Reinschmidt, K.F., 2010. Probabilistic forecasting of project duration using Kalman filter and the earned value method. *Journal of Construction Engineering and Management,* **136**(8), pp. 834-843.

Kim, E., Wells, W.G. and Duffey, M.R., 2003. A model for effective implementation of Earned Value Management methodology. *International Journal of Project Management,* **21**(5), pp. 375-382.

Kim, J., Koo, C., Kim, C., Hong, T. and Park, H.S., 2015. Integrated CO 2, cost, and schedule management system for building construction projects using the earned value management theory. *Journal of Cleaner Production,* **103**, pp. 275-285.

Kim, S., Park, C., Lee, S. and Son, J., 2008. Integrated cost and schedule control in the Korean construction industry based on a modified work-packaging model. *Canadian journal of civil engineering,* **35**(3), pp. 225-235.

Lauras, M., Marques, G. and Gourc, D., 2010. Towards a multi-dimensional project Performance Measurement System. *Decision Support Systems,* **48**(2), pp. 342-353.

Lipke, W., 2016. Examination of the Threshold for the To Complete Indexes. *The Measurable News,* **1**, pp. 9-14.

Lipke, W., 2006. Earned schedule leads to improved forecasting, *3rd International Conference on Project Management (ProMAC 2006)* 2006.

Lipke, W., 2003. Schedule is different. *The Measurable News,* **31**(4), pp. 31-34.

Lipke, W., Zwikael, O., Henderson, K. and Anbari, F., 2009. Prediction of project outcome: The application of statistical methods to earned value management and earned schedule performance indexes. *International Journal of Project Management,* **27**(4), pp. 400-407.

Martinelli, R.J. and Milosevic, D.Z., 2016. *Project Management Toolbox*. 2nd ed. John Wiley & Sons.

McConnell, D.R., 1985. Earned value technique for performance measurement. *Journal of Management in Engineering,* **1**(2), pp. 79-94.

Mosaic, 2012. *Earned Value Formulae.* [PDF]. Available at: https://mosaicprojects.com.au/WhitePapers/WP1081_Earned_Value.pdf.

Nabavi, A. and Rouhani, S., 2009. *SAP Project System*. [PDF]. Available at: http://www.sid.ir/FileServer/SE/137E20090101.

Naeni, L.M. and Salehipour, A., 2011. Evaluating fuzzy earned value indices and estimates by applying alpha cuts. *Expert Systems with Applications,* **38**(7), pp. 8193-8198.

Narbaev, T. and De Marco, A., 2014. An earned schedule-based regression model to improve cost estimate at completion. *International Journal of Project Management,* **32**(6), pp. 1007-1018.

Nassar, K.M., Gunnarsson, H.G. and Hegab, M.Y., 2005. Using Weibull analysis for evaluation of cost and schedule performance. *Journal of Construction Engineering and Management,* **131**(12), pp. 1257-1262.

Noori, S., Bagherpour, M. and Zareei, A., 2008. Applying fuzzy control chart in earned value analysis: a new application. *World Applied Sciences Journal,* **3**(4), pp. 684-690.

Pajares, J. and Lopez-Paredes, A., 2011. An extension of the EVM analysis for project monitoring: The Cost Control Index and the Schedule Control Index. *International Journal of Project Management,* **29**(5), pp. 615-621.

Paquin, J.P., Couillard, J. and Ferrand, D.J., 2000. Assessing and controlling the quality of a project end product: The earned quality method. *IEEE Transactions on Engineering Management,* **47**(1), pp. 88-97.

Project Management Institute, 2013. A *Guide to the Project Management Body of Knowledge (PMBOK® Guide).* 5th ed. Newtown Square (PA): Project Management Institute.

Project Management Institute, 2008. *A Guide to the Project Management Body of Knowledge (PMBOK® Guide).* 4th ed. Newtown Square (PA): Project Management Institute.

Project Management Institute, 2006. *Practice Standard for Work Breakdown Structures.* 2nd ed. Newtown Square (PA): Project Management Institute.

Project Management Institute, 2005. *Practice Standard for Earned Value Management*. Newtown Square (PA): Project Management Institute.

Project Management Institute, 2000. A Guide to the Project Management Body of Knowledge (PMBOK® Guide). 2000 ed. Newtown Square (PA): Project Management Institute.

Raby, M., 2000. Project management via earned value. *Work study,* **49**(1), pp. 6-10.

Rozenes, S., Vitner, G. and Spraggett, S., 2004. MPCS: Multidimensional project control system. *International Journal of Project Management,* **22**(2), pp. 109-118.

Ruskin, A.M., 2004. Two issues concerning the use of earned value measurements. *Engineering Management Journal,* **16**(3), pp. 26-30.

Salari, M., Bagherpour, M. and Kamyabniya, A., 2014. Fuzzy extended earned value management: A novel perspective. *Journal of Intelligent & Fuzzy Systems,* **27**(3), pp. 1393-1406.

Salari, M., Bagherpour, M. and Reihani, M.H., 2015. A time-cost trade-off model by incorporating fuzzy earned value management: A statistical based approach. *Journal of Intelligent & Fuzzy Systems,* **28**(4), pp. 1909-1919.

Stimpson, C.B., 2007. *A Review of the Validity of Current Project Performance Reports and the Identification of Areas Needing Improvement.* [PDF]. Available at: http://earnedschedule.com/Docs/Review%20of%20Project%20Perf%20Reports%20-%20C%20Stimpson.pdf.

Stumpe, F., 2013. *Course Project Management in practice.* BoD–Books on Demand.

Taylor, J., 2008. *Project scheduling and cost control: planning, monitoring and controlling the baseline.* J. Ross Publishing.

Vanhoucke, M., 2014. *Integrated Project Management and Control.* Springer.

Vanhoucke, M., 2009. *Measuring time: Improving project performance using earned value management.* Springer Science & Business Media.

Vanhoucke, M., Andrade, P., Salvaterra, F. and Batselier, J., 2015. Introduction to earned duration. *The Measurable News,* **2**, pp. 15-27.

Vanhoucke, M. and Vandevoorde, S., 2009. Forecasting a project's duration under various topological structures. *The Measurable News,* **1**, pp. 26-30.

Vanhoucke, M. and Vandevoorde, S., 2008. Earned value forecast accuracy and activity criticality. *The Measurable News,* **3**, pp. 13-16.

Vanhoucke, M. and Vandevoorde, S., 2007. A simulation and evaluation of earned value metrics to forecast the project duration. *Journal of the Operational Research Society,* **58**(10), pp. 1361-1374.

Vandevoorde, S. and Vanhoucke, M., 2006. A comparison of different project duration forecasting methods using earned value metrics. International Journal of Project Management, **24**(4), pp. 289-302.

Vitner, G., Rozenes, S. and Spraggett, S., 2006. Using data envelope analysis to compare project efficiency in a multi-project environment. *International Journal of Project Management,* **24**(4), pp. 323-329.

Warburton, R.D.H., 2014. A new schedule estimation technique for construction projects. *Organization, Technology & Management in Construction: An International Journal,* **6**(3), pp 1075-1082. 0-0.

Warburton, R.D.H., 2011. A time-dependent earned value model for software projects. *International Journal of Project Management,* **29**(8), pp. 1082-1090.

Warburton, R.D.H. and Cioffi, D.F., 2016. Estimating a project's earned and final duration. *International Journal of Project Management,* **34**(8), pp. 1493-1504.

Wauters, M. and Vanhoucke, M., 2014. Study of the stability of earned value management forecasting. *Journal of Construction Engineering and Management,* **141**(4), pp. 04014086.

Wilkens, T.T., 1999. *Earned value, clear and simple.* [PDF]. Available at: http://www.dtic.mil/get-tr-doc/pdf?AD=ADA402619.

Willems, L.L. and Vanhoucke, M., 2015. Classification of articles and journals on project control and earned value management. *International Journal of Project Management,* **33**(7), pp. 1610-1634.

Wood, D.A., 2017. High-level integrated deterministic, stochastic and fuzzy cost-duration analysis aids project planning and monitoring, focusing on uncertainties and earned value metrics. *Journal of Natural Gas Science and Engineering,* **37**, pp. 303-326.

List of Appendices

Appendix 1. Requirements Classification and Prioritization Table

Table 1-1. Requirements Classification and Prioritization

Requirements		Requirement Type					Requirement Prioritization		
#	**Description**	**Constraint**	**Functional**	**Non-functional**	**Initial**	**Ad Interim**	**Critical**	**Conditional**	**Optional**
1.	Excel based	✓			✓		✓		
2.	Numeric and graphic representation of metrics, performance measures and forecasts available		✓		✓		✓		
3.	One report view with most relevant performance indicators readily available at one glance		✓			✓	✓		
4.	Can be used for large projects with several control accounts and review periods		✓			✓	✓		
5.	Enables consideration of changes in scope		✓		✓		✓		
6.	Enables adjustment as per project needs		✓			✓			✓
7.	Possibility to add new functionalities		✓		✓				✓
8.	Visual representation should facilitate readability and highlight the deviations to the baseline			✓		✓		✓	
9.	Simple and easy to use interface			✓	✓			✓	

Appendix 2. Screen Captures of EVM Tool

Planned Value

WBS	TASK	TBC	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Insert
1.1	werfinricht	867102	867102	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1.2	grondwerk	533489,4	142296,658	271149,016	99333,2397	20710,5293	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1.3	100 ruwbo	5887942	9394,74023	26178,6699	620995,031	1188922,28	1010612,81	252653,203	757959,609	0	505306,406	757959,609	505306,406	252653,203	0	0	0	0	0	0	0	
1.4	150 dak	597815,1	0	0	0	0	0	0	232877,578	20480,4297	0	0	46575,5195	66991,6563	230889,938	0	0	0	0	0	0	
1.5	180 gevel	3310363	0	0	0	0	0	0	1071966	0	2053,96997	491317,75	491317,75	1250627	0	0	0	3080,95996	0	0	0	
1.6	205 gelijkv	520800,3	0	0	0	0	0	0	0	0	0	64379,4023	88472,6172	10113,6601	33474,8196	324359,808	0	0	0	0	0	
1.7	210 eerste	559972,2	0	0	0	0	0	0	0	0	0	64378,4023	88472,6172	197745,348	4682,93018	170884,16	33808,7695	0	0	0	0	
1.8	220 tweed	52785,16	0	0	0	0	0	0	0	0	0	0	14638,2695	38146,8906	0	0	0	0	0	0	0	
1.9	230 derde	559972,2	0	0	0	0	0	0	0	0	0	152851,02	8611,62012	278326,158	49173,3705	33808,7695	0	0	37201,2891	0	0	
1.10	240 vierde	559972,2	0	0	0	0	0	0	0	0	0	152851,02	8611,62012	315527,447	49173,3705	33808,7695	0	0	0	0	0	
1.11	250 vijfde	559972,2	0	0	0	0	0	0	0	0	0	152851,02	8611,62012	226335,017	89192,4302	60482,14	22500	0	0	0	0	
1.12	260 zesde	559972,2	0	0	0	0	0	0	0	0	0	152851,02	8611,62012	226335,017	89192,4302	60482,14	22500	0	0	0	0	
1.13	270 zeven	559972,2	0	0	0	0	0	0	0	0	0	64378,4023	88472,6172	46357,1392	193272,428	84509,5	60482,14	22500	0	0	0	
1.14	280 achtst	559972,2	0	0	0	0	0	0	0	0	0	64378,4023	88472,6172	9155,8501	230473,717	84509,5	60482,14	22500	0	0	0	
1.15	290 negen	559972,2	0	0	0	0	0	0	0	0	0	0	64378,4023	88472,6172	41884,2192	197745,348	133682,87	33808,7695	0	0	0	
1.16	300 tiende	559972,2	0	0	0	0	0	0	0	0	0	0	64378,4023	88472,6172	41884,2192	197745,348	133682,87	33808,7695	0	0	0	
1.17	310 elfde	559972,2	0	0	0	0	0	0	0	0	0	0	0	64378,4023	125673,906	4682,93018	314764,218	50472,7699	0	0	0	
1.18	320 twaalf	559972,2	0	0	0	0	0	0	0	0	0	0	0	64378,4023	125673,906	4682,93018	314764,218	50472,7699	0	0	0	
1.19	330 dertie	559973,2	0	0	0	0	0	0	0	0	0	0	0	0	152851,02	41884,2192	0	282254,848	49173,3705	11309,7695	22500	
1.20	340 veerti	322737,5	0	0	0	0	0	0	0	0	0	0	0	0	0	133544,398	152725,359	0	36467,7705	0	0	
1.21	buitenaanl	194720,8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	194720,828	0	0	0	0	
1.22	testen en	422387	0	0	0	0	0	0	0	0	0	0	0	0	0	0	99385,1797	99385,1797	223616,648	0	0	
		0																				
Summa																						19429810,5
Total Budgeted Cost		**19429811**	1 018 793 €	297 328 €	720 328 €	1 209 633 €	1 010 613 €	252 653 €	2 062 803 €	20 480 €	507 360 €	2 118 196 €	1 574 932 €	3 224 016 €	1 457 493 €	1 433 130 €	1 543 499 €	598 284 €	346 459 €	11 310 €	22 500 €	
Cumulative Planned Value (PV)			1 018 793 €	1 316 121 €	2 036 449 €	3 246 082 €	4 256 695 €	4 509 348 €	6 572 151 €	6 592 632 €	7 099 992 €	9 218 188 €	10 793 120 €	14 017 136 €	15 474 629 €	16 907 759 €	18 451 258 €	19 049 542 €	19 396 001 €	19 407 311 €	19 429 811 €	

Figure 2-1. Screen capture of Planned Value tab in the EVM Tool

Earned Value | **Progress recorded until:** 19

WBS	TASK	TBC	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Inser
1.1	werfinrichting	867102	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	
1.2	grondwerken en funderin	533489,4	27 %	77 %	96 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	
1.3	100 ruwbouw	5887942	0 %	0 %	16 %	18 %	40 %	49 %	61 %	74 %	83 %	96 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	
1.4	150 dak	597815,1	0 %	0 %	0 %	0 %	0 %	0 %	39 %	39 %	42 %	42 %	85 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	
1.5	180 gevel	3310363	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	15 %	15 %	30 %	68 %	68 %	100 %	100 %	100 %	100 %	100 %	100 %	
1.6	205 gelijkvloers	520800,3	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	13 %	30 %	30 %	34 %	55 %	100 %	100 %	100 %	100 %	
1.7	210 eerste verdieping	559972,2	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	28 %	28 %	28 %	32 %	91 %	100 %	100 %	100 %	100 %	
1.8	220 tweede verdieping	52785,16	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	28 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	
1.9	230 derde verdieping	559972,2	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	28 %	28 %	28 %	81 %	91 %	100 %	100 %	100 %	100 %	100 %	100 %	
1.10	240 vierde verdieping	559972,2	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	28 %	28 %	28 %	81 %	91 %	96 %	100 %	100 %	100 %	100 %	100 %	
1.11	250 vijfde verdieping	559972,2	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	28 %	28 %	28 %	79 %	87 %	94 %	100 %	100 %	100 %	100 %	100 %	
1.12	260 zesde verdieping	559972,2	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	28 %	28 %	28 %	79 %	81 %	94 %	100 %	100 %	100 %	100 %	100 %	
1.13	270 zevende verdieping	559972,2	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	12 %	28 %	28 %	62 %	79 %	91 %	100 %	100 %	100 %	100 %	100 %	
1.14	280 achtste verdieping	559972,2	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	5 %	28 %	28 %	62 %	79 %	91 %	100 %	100 %	100 %	100 %	100 %	
1.15	290 negende verdieping	559972,2	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	28 %	28 %	62 %	63 %	87 %	94 %	100 %	100 %	100 %	100 %	
1.16	300 tiende verdieping	559972,2	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	28 %	28 %	62 %	63 %	87 %	94 %	100 %	100 %	100 %	100 %	
1.17	310 elfde verdieping	559972,2	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	28 %	28 %	30 %	36 %	87 %	96 %	100 %	100 %	100 %	
1.18	320 twaalfde verdieping	559972,2	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	28 %	28 %	30 %	36 %	87 %	94 %	100 %	100 %	100 %	
1.19	330 dertiende verdieping	559973,2	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	28 %	28 %	28 %	30 %	72 %	94 %	96 %	100 %	100 %	
1.20	340 veertiende verdiepin	322737,5	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	21 %	58 %	89 %	89 %	95 %	95 %	100 %	100 %	100 %	
1.21	buitenaanleg	194720,8	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	2 %	48 %	92 %	100 %	100 %	
1.22	testen en opleveringen	422387	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	24 %	47 %	100 %	100 %	100 %	
-	-	0																				
Summa																						
	Cumulative Earned Value (EV)		1009399	1289942	2325429	2442850	3751389	4256695	5249586	6007546	7753530	9042882	1,1E+07	1,4E+07	1,5E+07	1,7E+07	1,8E+07	1,9E+07	1,9E+07	1,9E+07	1,9E+07	0

Figure 2-2. Screen capture of % Completion tab in the EVM Tool

Actual Cost																							
WBS	**TASK**	**TBC**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**Inser**
1.1	werfinrichting	867102		962508	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1.2	grondwerken en funderin	533489,4		149343	273670	100429	21887,6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1.3	100 ruwbouw	5887942		0	10210,1	978989	97603,5	1379029	533425	800137	800137	533425	800137	266712	0	0	0	0	0	0	0	0	
1.4	150 dak	597815,1		0	0	0	0	0	0	229682	0	20868,7	0	250931	97388,5	0	0	0	0	0	0	0	
1.5	180 gevel	3310363		0	0	0	0	0	0	2442,24	0	482761	0	482761	1228847	0	1056961	0	0	0	0	0	
1.6	205 gelijkvloers	520800,3		0	0	0	0	0	0	0	0	0	0	48683,7	626109	0	21340,1	163192	233059	0	0	0	
1.7	210 eerste verdieping	559972,2		0	0	0	0	0	0	0	0	0	0	144517	0	0	21340,1	405417	50207,8	0	0	0	
1.8	220 tweede verdieping	52785,16		0	0	0	0	0	0	0	0	0	0	15026,5	40312,3	0	0	0	0	0	0	0	
1.9	230 derde verdieping	559972,2		0	0	0	0	0	0	0	0	144517	0	0	328897	97860,8	50207,8	0	0	0	0	0	
1.10	240 vierde verdieping	559972,2		0	0	0	0	0	0	0	0	144517	0	0	328897	97860,8	27513,7	22694,1	0	0	0	0	
1.11	250 vijfde verdieping	559972,2		0	0	0	0	0	0	0	0	144517	0	0	316362	50849,9	75633,7	34119,4	0	0	0	0	
1.12	260 zesde verdieping	559972,2		0	0	0	0	0	0	0	0	144517	0	0	316362	12534,4	113949	34119,4	0	0	0	0	
1.13	270 zevende verdieping	559972,2		0	0	0	0	0	0	0	0	48683,7	95833,6	0	184635	131728	110395	50207,8	0	0	0	0	
1.14	280 achtste verdieping	559972,2		0	0	0	0	0	0	0	0	26507,9	118009	0	184635	131728	110395	50207,8	0	0	0	0	
1.15	290 negende verdieping	559972,2		0	0	0	0	0	0	0	0	0	144517	0	184635	8805,75	193285	56120,1	34119,4	0	0	0	
1.16	300 tiende verdieping	559972,2		0	0	0	0	0	0	0	0	0	144517	0	184635	8805,75	193285	56120,1	34119,4	0	0	0	
1.17	310 elfde verdieping	559972,2		0	0	0	0	0	0	0	0	0	0	144517	0	8805,75	38315,5	339605	67545,4	22694,1	0	0	
1.18	320 twaalfde verdieping	559972,2		0	0	0	0	0	0	0	0	0	0	144517	0	8805,75	38315,5	339605	56120,1	34119,4	0	0	
1.19	330 dertiende verdieping	559973,2		0	0	0	0	0	0	0	0	0	0	144517	0	0	8805,75	235485	198556	29208,1	22694,1	0	
1.20	340 veertiende verdiepin	322737,5		0	0	0	0	0	0	0	0	0	0	69432,4	118118	109769	0	40031,6	0	16088,5	0	0	
1.21	buitenaanleg	194720,8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	328391	0	0	0	0	
1.22	testen en opleveringen	422387		0	0	0	0	0	0	0	0	0	0	0	0	0	0	155951	164235	361245	0	0	
-	-	0																					
Summa																							
	Total Actual Cost			**1111851**	283881	1079418	119491	1379029	533425	1032261	800137	1690316	1303015	1711617	4139832	667553	2059744	2311266	837962	463355	22694,1	0	0
	Cumulative Actual Cost (AC)			1111851	1395732	2475149	2594640	3973669	4507094	5539355	6339492	8029808	9332823	1,1E+07	1,5E+07	1,6E+07	1,8E+07	2E+07	2,1E+07	2,2E+07	2,2E+07	2,2E+07	2,2E+07

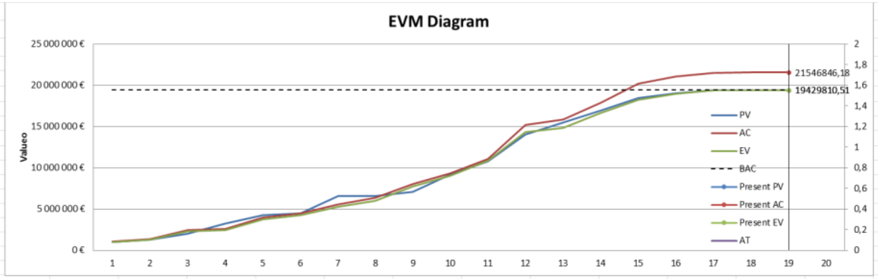
Figure 2-3. Screen capture of Actual Cost tab in the EVM Tool

Total Budgeted Cost 19429811		1 018 793 €	297 328 €	720 328 €	1 209 633 €	1 010 613 €	252 653 €	2 062 803 €	20 480 €	507 360 €	2 118 196 €	1 574 932 €	3 224 016 €	1 457 493 €	1 433 130 €	1 543 499 €	598 284 €	346 459 €	11 310 €	22 500 €
Cumulative Planned Value (PV)		1 018 793 €	1 316 121 €	2 036 449 €	3 246 082 €	4 256 695 €	4 509 348 €	6 572 151 €	6 592 632 €	7 099 992 €	9 218 188 €	##########	##########	##########	##########	##########	##########	##########	##########	##########
Cumulative Actual Cost (AC)		1 111 851 €	1 395 732 €	2 475 149 €	2 594 640 €	3 973 669 €	4 507 094 €	5 539 355 €	6 339 492 €	8 029 808 €	9 332 823 €	##########	##########	##########	##########	##########	##########	##########	##########	##########
Cumulative Earned Value (EV)		1 009 399 €	1 289 942 €	2 325 429 €	2 442 850 €	3 751 389 €	4 256 695 €	5 249 586 €	6 007 546 €	7 753 530 €	9 042 882 €	##########	##########	##########	##########	##########	##########	##########	##########	##########
ES metrics																				
Planned Duration (PD)		19																		
Earned Schedule (ES)		0,99077856	1,91195347	3,23889879	3,33597044	4,5	5	6,3588505	6,72629205	9,30853519	9,91723774	11,0092157	12,2059464	12,5487525	13,7953515	14,8704619	15,9158464	16,9876814	19	19
Actual Time (AT)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Periodic Earned Schedule		0,99077856	0,92117491	1,32694531	0,09707166	1,16402956	0,5	1,3588505	0,36744155	2,58224314	0,60870255	1,091978	1,19673064	0,34280612	1,24659904	1,0751104	1,04538443	1,07183503	2,01231861	0
Time Performance Measures																				
Schedule Variance (SV)		-9394,7402	-26178,67	288979,812	-803231,94	-505306,41	-252653,2	-1322565,2	-585086,05	653538,019	-175306,68	29711,6938	300165,338	-657689,95	-293287,84	-199941,82	-50347,783	-4267,8935	22500	-3,725E-09
Schedule Pefromance Indicator (SPI)		0,99077856	0,98010922	1,14190376	0,75255342	0,88129138	0,94397124	0,79876221	0,91125152	1,09204771	0,98098252	1,00275284	1,02141417	0,95749882	0,98265365	0,98916378	0,99735701	0,99977996	1,00115936	1
SPI_{per}		0,99077856	0,94355073	1,43752063	0,09707166	1,29479691	2	0,48133102	37,0089701	3,44131022	0,60870255	1,13017604	1,08388718	0,34280612	1,2542701	1,06047691	1,25003848	1,1330024	3,36679389	0
Cost Performance Measures																				
Cost Variance (CV)		-102452,43	-105789,22	-149719,99	-151790,08	-222280,44	-250398,94	-289768,9	-331946,65	-276278,15	-289941,84	-221608,6	-866970,64	-1034886,5	-1297098,2	-1971519,2	-2061603,1	-2132419,2	-2117035,7	-2117035,7
Cost Performance Indicator (CPI)		0,90785418	0,92420519	0,93951072	0,9414986	0,94406166	0,94444337	0,94768905	0,94763829	0,96559343	0,96893311	0,97993483	0,94290338	0,934715	0,92758322	0,90251024	0,90211182	0,900929	0,90174731	0,90174731
CPI_{per}		0,90785418	0,9882458	0,9593014	0,98267579	0,94888405	0,94728686	0,96186046	0,94728686	1,03293379	0,98951379	1,03992321	0,84410913	0,74846072	0,87269693	0,70820272	0,89249644	0,84716674	1,67786397	#JAKO/0!
Time Performance Measures (ES)																				
Schedule Variance (SV(t))		-0,0092214	-0,0880465	0,23889879	-0,6640296	-0,5	-1	-0,6411495	-1,2737079	0,30853519	-0,0827623	0,00921574	0,20594637	-0,4512475	-0,2046485	-0,1295381	-0,0841536	-0,0123186	1	0
Schedule Pefromance Indicator (SPI(t))		0,99077856	0,95597674	1,07963293	0,83399261	0,9	0,83333333	0,90840721	0,84078651	1,03428169	0,99172377	1,00083779	1,0171622	0,96528865	0,98538225	0,99136413	0,9947404	0,99927538	1,05555556	1
$SPI(t)_{per}$		0,99077856	0,92117491	1,32694531	0,09707166	1,16402956	0,5	1,3588505	0,36744155	2,58224314	0,60870255	1,091978	1,19673064	0,34280612	1,24659904	1,0751104	1,04538443	1,07183503	2,01231861	0
Cost Forecasts, EAC(€)																				
Estimate at Completion (EAC_1(€))		19532262,9	19535599,7	19579530,5	19581600,6	19652091	19680209,5	19719579,4	19761757,2	19706088,7	19719752,3	19651419,1	20296781,1	20464697	20726908,7	21401329,8	21491413,7	21562229,7	21546846,2	21546846,2
Estimate at Completion (EAC_2(€))		21401906,7	21023264,9	20680775,8	20637110,3	20581082,1	20572763,9	20502305,5	20503403,8	20122144,4	20052788,4	19827655,8	20606364,3	20786882,2	20946703,4	21528631,5	21538139,9	21566416,9	21546846,2	21546846,2
Estimate at Completion (EAC_3(€))		19610648,9	19824127,8	17015278,6	25818513,4	22046976,8	20583053,6	24324899,6	21322115,9	17792089,4	19806479,8	19376470,3	19022460,3	20292255,2	19772796,3	19642662,7	19481299,4	19434086,8	19407310,5	19429810,5
Estimate at Completion (EAC_4(€))		19610648,9	20324564,2	17996682	23297341,3	21588678,3	23315772,6	21388877,4	23109089,4	18785801,5	19591958	19413546	19101978,6	20128497,8	19718043,9	19599065,5	19532543,9	19443900	18407188,9	19429810,5
Estimate at Completion (EAC_5(€))		21590751,6	21421594,9	18418372,5	26569642,7	22818075,7	21526330,7	24272027,1	21882853,4	19102892,4	20260607,2	19803543,5	20492688,9	21005938,1	21000281,2	21542936,4	21539404,8	21566426,2	21546846,2	21546846,2
Estimate at Completion (EAC_6(€))		21590751,6	21927123,8	19337942,2	24228489,1	22426350,2	23785897,9	22010988,3	23185518,4	19721339	20142249,6	19820303,5	20514879,3	20964344,6	20991728,3	21540006,5	21540663,8	21566447,6	21546846,2	21546846,2
Estimate at Completion (EAC_7(€))		21037893,5	20788654,1	19928789,6	21391564,6	20804902,5	20574370,4	20987843,4	20613016,8	19813505,5	20026192,3	19786941,6	20517549,3	20762940,4	20911087,2	21504029	21528268,7	21565509,4	21546846,2	21546846,2
Estimate at Completion (EAC_8(€))		21037893,5	20889238,6	20153453,8	21058779,7	20737564,4	20959885,1	20627385,7	20830185,9	19952518,2	20002594,8	19790344,1	20522284,7	20754807,8	20909344,2	21503416,4	21528534,5	21565513,9	21546846,2	21546846,2
Estimate at Completion (EAC_{min}(€))		19532262,9	19535599,7	17015278,6	19581600,6	19652091	19680209,5	19719579,4	19761757,2	17792089,4	19591958	19376470,3	19022460,3	20128497,8	19718043,9	19599065,5	19481299,4	19434086,8	18407188,9	19429810,5
Estimate at Completion (EAC_{max}(€))		21590751,6	21927123,8	20680775,8	26569642,7	22818075,7	23785897,9	24324899,6	23185518,4	20122144,4	20260607,2	19827655,8	20606364,3	21005938,1	21000281,2	21542936,4	21540663,8	21566447,6	21546846,2	21546846,2
Variance at Completion (VAC)																				
Variance at Completion (VAC_1)		-102452,43	-105789,22	-149719,99	-151790,08	-222280,44	-250398,94	-289768,9	-331946,65	-276278,15	-289941,84	-221608,6	-866970,64	-1034886,5	-1297098,2	-1971519,2	-2061603,1	-2132419,2	-2117035,7	-2117035,7
Variance at Completion (VAC_2)		-1972096,2	-1593454,4	-1250965,3	-1207299,8	-1151271,5	-1142953,4	-1072495	-1073593,3	-692333,93	-622977,86	-397845,33	-1176553,8	-1357071,7	-1516892,8	-2098821	-2108329,4	-2136606,4	-2117035,7	-2117035,7
Variance at Completion (VAC_3)		-180838,38	-394317,29	2414531,94	-6388702,9	-2617166,3	-1153243	-4895089,1	-1892305,4	1637721,08	-376669,28	53340,2535	407350,196	-862444,73	-342985,77	-212852,15	-51488,915	-4276,2739	22500	0
Variance at Completion (VAC_4)		-180838,38	-894753,64	1433128,51	-3867530,8	-2158867,8	-3885962,1	-1959066,9	-3679278,8	644008,982	-162147,46	16264,5611	327831,936	-698687,26	-288233,38	-169255	-102733,42	-14089,516	1022621,61	0
Variance at Completion (VAC_5)		-2160941,1	-1991784,4	1011438,01	-7139832,2	-3388265,1	-2096520,2	-4842216,6	-2453042,9	326918,099	-830796,74	-373732,96	-1062878,4	-1576127,6	-1570470,7	-2113125,9	-2109594,3	-2136615,7	-2117035,7	-2117035,7
Variance at Completion (VAC_6)		-2160941,1	-2497313,3	91868,3384	-4798678,5	-2996539,7	-4356087,4	-2581177,8	-3755707,9	-291528,53	-712439,11	-390492,97	-1085068,8	-1534534,1	-1561917,8	-2110195,9	-2110853,3	-2136637,1	-2117035,7	-2117035,7
Variance at Completion (VAC_7)		-1608082,9	-1358843,6	-498979,1	-1961754,1	-1375092	-1144559,8	-1558032,9	-1183206,3	-383694,94	-596381,83	-357131,1	-1087738,8	-1333129,9	-1481276,7	-2074218,5	-2098458,2	-2135698,9	-2117035,7	-2117035,7
Variance at Completion (VAC_8)		-1608082,9	-1459428,1	-723643,31	-1628969,2	-1307753,9	-1530074,6	-1197575,2	-1400375,4	-522707,64	-572784,25	-360533,6	-1092474,2	-1324997,3	-1479533,7	-2073605,9	-2098723,9	-2135703,4	-2117035,7	-2117035,7
Variance at Completion (VAC_{min})		-2160941,1	-2497313,3	-1250965,3	-7139832,2	-3388265,1	-4356087,4	-4895089,1	-3755707,9	-692333,93	-830796,74	-397845,33	-1176553,8	-1576127,6	-1570470,7	-2113125,9	-2110853,3	-2136637,1	-2117035,7	-2117035,7
Variance at Completion (VAC_{min})		-102452,43	-105789,22	2414531,94	-151790,08	-222280,44	-250398,94	-289768,9	-331946,65	1637721,08	-162147,46	53340,2535	407350,196	-698687,26	-288233,38	-169255	-51488,915	-4276,2739	1022621,61	0
Estimates to Completion, ETC(€)																				
Estimate to Completion (ETC_1(€))		##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	8 606 979 €	5 112 509 €	4 612 871 €	2 815 339 €	1 178 495 €	430 617 €	38 078 €	0 €	0 €
Estimate to Completion (ETC_2(€))		##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	9 004 824 €	6 289 063 €	5 969 943 €	4 332 232 €	3 277 316 €	2 538 946 €	2 174 684 €	2 117 036 €	2 117 036 €
Estimate to Completion (ETC_3(€))		##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########
Estimate to Completion (ETC_4(€))		##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########
Estimate to Completion (ETC_5(€))		##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########
Estimate to Completion (ETC_6(€))		##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########
Estimate to Completion (ETC_7(€))		##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########
Estimate to Completion (ETC_8(€))		##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########	##########
Performance to Complete forecasts																				
To-Complete Performance Index ($TCPI_{BAC}$)		1,005593	1,00586607	1,00883061	1,00901625	1,01438137	1,01677972	1,02086101	1,02535818	1,02423492	1,02871568	1,026428	1,20420748	1,28923725	1,85434268	-1,4860761	-0,2640222	-0,0181812	0	0
Time Forecasts EAC(t)																				
Estimate at Completion (EAC_1(t))		19,0092214	19,0880465	18,7611012	19,6640296	19,5	20	19,6411495	20,2737079	18,6914648	19,0827623	18,9907843	18,7940536	19,4512475	19,2046485	19,1295381	19,0841536	19,0123186	18	19
Estimate at Completion (EAC_2(t))		19,176838	19,8749606	17,598574	22,7819764	21,1111111	22,8	20,91573	22,5978888	18,3702373	19,1585606	18,9840952	18,6794201	19,6832315	19,2818573	19,1655109	19,1004608	19,0137778	18	19
Estimate at Completion (EAC_3(t))		21,0217594	21,3409005	18,5384858	23,9490221	22,0657403	23,7882555	21,6838564	23,4044945	18,7041228	19,4522114	19,1475778	19,0838861	20,1500206	19,694214	19,6154721	19,4368919	19,2352237	18	19
Estimate at Completion (EAC_{min}(t))		19,0092214	19,0880465	17,598574	19,6640296	19,5	20	19,6411495	20,2737079	18,3702373	19,0827623	18,9840952	18,6794201	19,4512475	19,2046485	19,1295381	19,0841536	19,0123186	18	19
Estimate at Completion (EAC_{max}(t))		21,0217594	21,3409005	18,7611012	23,9490221	22,0657403	23,7882555	21,6838564	23,4044945	18,7041228	19,4522114	19,1475778	19,0838861	20,1500206	19,694214	19,6154721	19,4368919	19,2352237	18	19

Figure 2-4. Screen capture of Numeric Report tab in the EVM Tool including metrics, performance measures and forecasts for total project

Report

Project Name:			**Status Date:**		
EVM Metrics		**Budget (TBC)**	**Periodic performance**		
Cumulative Planned Value (PV)	19429810,51	19429810,51	CPI_{per}	#JAKO/0!	
Cumulative Actual Cost (AC)	21546846,18		$SPI(t)_{per}$	0	
Cumulative Earned Value (EV)	19429810,51	**Review period (AT)**			
Earned Schedule (ES)	19	19	**Performance to Complete**		
			To-Complete Performance Index ($TCPI_{BAC}$)	0	
Cost performance		**Planned Duration (PD)**			
Cost Variance (CV)	-2117035,7	19	**Selected COST Estimate at Completion**		
Cost Performance Indicator (CPI)	0,9017473		Estimate at Completion (EAC2(€))	21546846	
			Estimate to Completion (ETC2(€))	0	
Time performance			Variance at Completion (VAC2(€))	-2117035,669	
Schedule Variance (SV(t))	0				
Schedule Pefromance Indicator (SPI(t))	1		**Selected TIME Estimate at Completion**		
			Estimate at Completion (EAC1(t))	19	



WBS	TASK	TBC	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Insert
1.1	werfinrichting	867102	867102																			
1.2	grondwerken en funderin	533489,4	142297	271149	99333	20711																
1.3	100 ruwbouw	5887942	9395	26179	620995	1188922	1010613	252653	757960		505306	757960	505306	252653								
1.4	150 dak	597815,1							232878	20480			46576	66992	230890							
1.5	180 gevel	3310363							1071966		2054	491318	491318	1250627				3081				
1.6	205 gelijkvloers	520800,3										64379	88473	10114	33475	324360						
1.7	210 eerste verdieping	559972,2										64378	88473	197745	4683	170884	33809					
1.8	220 tweede verdieping	52785,16											14638	38147								
1.9	230 derde verdieping	559972,2										152851	8612	278326	49173	33809			37201			
1.10	240 vierde verdieping	559972,2										152851	8612	315527	49173	33809						
1.11	250 vijfde verdieping	559972,2										152851	8612	226335	89192	60482	22500					
1.12	260 zesde verdieping	559972,2										152851	8612	226335	89192	60482	22500					
1.13	270 zevende verdieping	559972,2										64378	88473	46357	193272	84510	60482	22500				
1.14	280 achtste verdieping	559972,2										64378	88473	9156	230474	84510	60482	22500				
1.15	290 negende verdieping	559972,2											64378	88473	41884	197745	133683	33809				
1.16	300 tiende verdieping	559972,2											64378	88473	41884	197745	133683	33809				
1.17	310 elfde verdieping	559972,2												64378	125674	4683	314764	50473				
1.18	320 twaalfde verdieping	559972,2												64378	125674	4683	314764	50473				
1.19	330 dertiende verdieping	559973,2													152851	41884		282255	49173	11310	22500	
1.20	340 veertiende verdiepin	322737,5														133544	152725		36468			
1.21	buitenaanleg	194720,8															194721					
1.22	testen en opleveringen	422387															99385	99385	223617			
-	-	-																				

Summa

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19		
Total Budgeted Cost	**19429811**	1 018 793	297 328	720 328	1 209 633	1 010 613	252 653	2 062 803	20 480	507 360	2 118 196	1 574 932	3 224 016	1 457 493	1 433 130	1 543 499	598 284	346 459	11 310	22 500		**22 500**
Cumulative Planned Value (PV)		1 018 793	1 316 121	2 036 449	3 246 082	4 256 695	4 509 348	6 572 151	6 592 632	7 099 992	9 218 188	10 793 120	14 017 136	15 474 629	16 907 759	18 451 258	19 049 542	19 396 001	19 407 311	19 429 811		**19 429 811**
Cumulative Actual Cost (AC)		1 111 851	1 395 732	2 475 149	2 594 640	3 973 669	4 507 094	5 539 355	6 339 492	8 029 808	9 332 823	11 044 440	15 184 272	15 851 826	17 911 569	20 222 835	21 060 797	21 524 152	21 546 846	21 546 846		**21 546 846**
Cumulative Earned Value (EV)		1 009 399	1 289 942	2 325 429	2 442 850	3 751 389	4 256 695	5 249 586	6 007 546	7 753 530	9 042 882	10 822 832	14 317 302	14 816 939	16 614 471	18 251 316	18 999 194	19 391 733	19 429 811	19 429 811		**19 429 811**
Earned Schedule (ES)		0,990778562	1,911953474	3,238898788	3,335970444	4,5	5	6,3588505	6,726292054	9,308535189	9,917237744	11,00921574	12,20594637	12,54875249	13,79535154	14,87046193	15,91584636	16,98768139	19	19		**19**
Cost performance																						
Cost Variance (CV)		-102452,43	-105789,22	-149719,99	-151790,08	-222280,44	-250398,94	-289768,9	-331946,65	-276278,15	-289941,84	-221608,6	-866970,64	-1034886,5	-1297098,2	-1971519,2	-2061603,1	-2132419,2	-2117035,7	-2117035,7		-2117035,7
Cost Performance Indicator (CPI)		0,9078542	0,9242052	0,9395107	0,9414986	0,9440617	0,9444434	0,9476891	0,9476383	0,9655934	0,9689331	0,9799348	0,9429034	0,934715	0,9275832	0,9025102	0,9021118	0,900929	0,9017473	0,9017473		0,90174731
Time performance																						
Schedule Variance (SV(t))		-0,0092214	-0,0880465	0,2388988	-0,6640296	-0,5	-1	-0,6411495	-1,2737079	0,3085352	-0,0827623	0,0092157	0,2059464	-0,4512475	-0,2046485	-0,1295381	-0,0841536	-0,0123186	1	0		0
Schedule Pefromance Indicator (SPI(t))		0,9907786	0,9559767	1,0796329	0,8339926	0,9	0,8333333	0,9084072	0,8407865	1,0342817	0,9917238	1,0008378	1,0171622	0,9652887	0,9853823	0,9913641	0,9947404	0,9992754	1,0555556	1		1
Periodic performance																						
CPI_{per}		0,9078542	0,9882458	0,9593014	0,9826758	0,9488841	0,9472869	0,9618605	0,9472869	1,0329338	0,9895138	1,0399232	0,8441091	0,7484607	0,8726969	0,7082027	0,8924964	0,8471667	1,677864	#JAKO/0!		#JAKO/0!
$SPI(t)_{per}$		0,9907786	0,9211749	1,3269453	0,0970717	1,1640296	0,5	1,3588505	0,3674416	2,5822431	0,6087026	1,091978	1,1967306	0,3428061	1,246599	1,0751104	1,0453844	1,071835	2,0123186	0		0
Performance to Complete																						
To-Complete Performance Index ($TCPI_{BAC}$)		1,005593	1,0058661	1,0088306	1,0090162	1,0143814	1,0167797	1,020861	1,0253582	1,0242349	1,0287157	1,026428	1,2042075	1,2892372	1,8543427	-1,4860761	-0,2640222	-0,0181812	0	0		0
Selected COST Estimate at Completion																						
Estimate at Completion (EAC2(€))		21401907	21023265	20680776	20637110	20581082	20572764	20502306	20503404	20122144	20052788	19827656	20606364	20786882	20946703	21528632	21538140	21566417	21546846	21546846		21546846,2
Variance at Completion (VAC2)		-1972096,2	-1593454,4	-1250965,3	-1207299,8	-1151271,5	-1142953,4	-1072495	-1073593,3	-692333,93	-622977,86	-397845,33	-1176553,8	-1357071,7	-1516892,8	-2098821	-2108329,4	-2136606,4	-2117035,7	-2117035,7		-2117035,7
Selected TIME Estimate at Completion																						
Estimate at Completion (EAC1(t))		19,009221	19,088047	18,761101	19,66403	19,5	20	19,64115	20,273708	18,691465	19,082762	18,990784	18,794054	19,451248	19,204648	19,129538	19,084154	19,012319	18	19		19

Figure 2-5. Screen capture of Summary Report tab in the EVM Tool

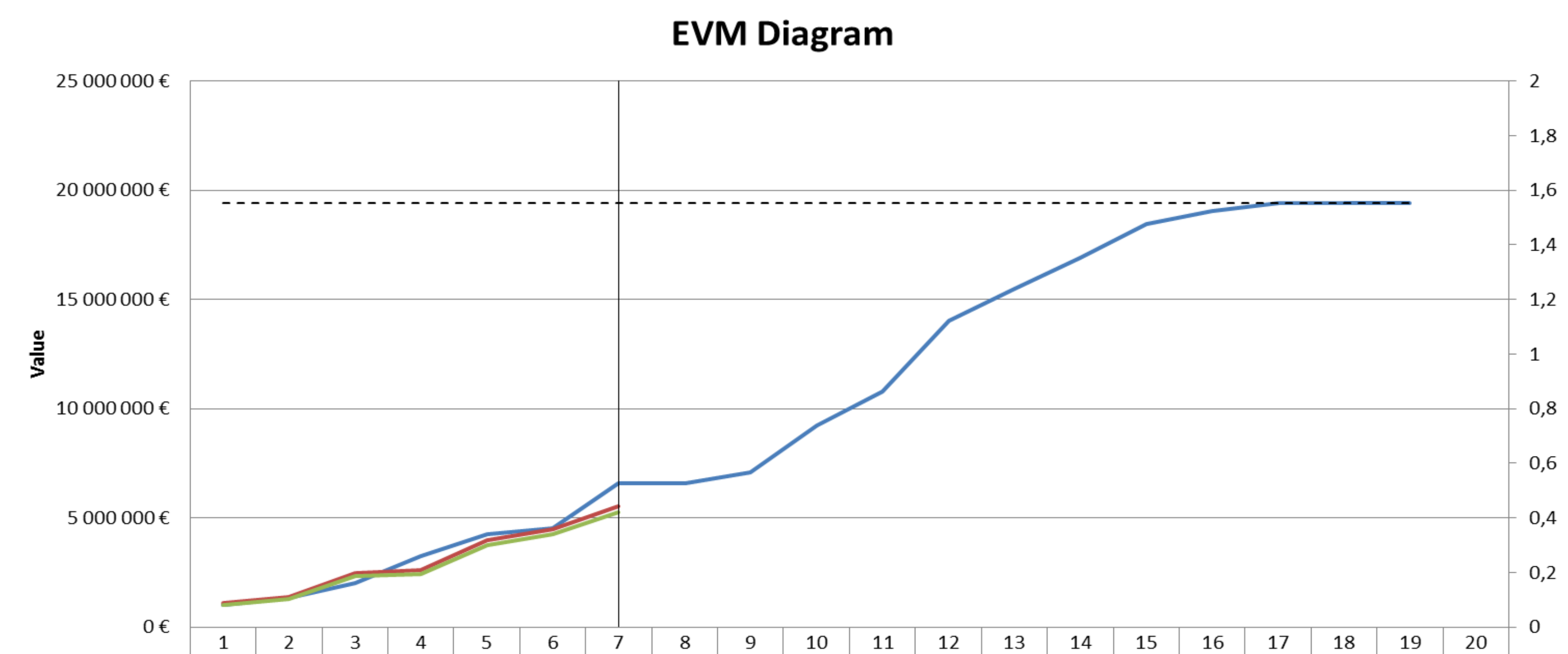
Changes to baseline

Past budgets (red fill = period < AT) shall not be increased.

WBS	TASK	TBC	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Insert
1.1	werfinricht	867102		867102	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1.2	grondwerk	533489,4		142296,6581	271149	99333,24	20710,53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1.3	100 ruwbo	5887942		9394,740234	26178,67	620995	1188922	1010613	252653,2	757959,6	0	505306,4	757959,6	505306,4063	252653,2	0	0	0	0	0	0	0	
1.4	150 dak	597815,1		0	0	0	0	0	0	232877,6	20480,43	0	0	46575,51953	66991,66	230889,9	0	0	0	0	0	0	
1.5	180 gevel	3310363		0	0	0	0	0	0	1071966	0	2053,97	491317,8	491317,75	1250627	0	0	0	3080,96	0	0	0	
1.6	205 gelijkv	520800,3		0	0	0	0	0	0	0	0	0	64379,4	88472,61719	10113,66	33474,82	324359,8	0	0	0	0	0	
1.7	210 eerste	559972,2		0	0	0	0	0	0	0	0	0	64378,4	88472,61719	197745,3	4682,93	170884,2	33808,77	0	0	0	0	
1.8	220 tweed	52785,16		0	0	0	0	0	0	0	0	0	0	14638,26953	38146,89	0	0	0	0	0	0	0	
1.9	230 derde	559972,2		0	0	0	0	0	0	0	0	0	152851	8611,620117	278326,2	49173,37	33808,77	0	0	37201,29	0	0	
1.10	240 vierde	559972,2		0	0	0	0	0	0	0	0	0	152851	8611,620117	315527,4	49173,37	33808,77	0	0	0	0	0	
1.11	250 vijfde	559972,2		0	0	0	0	0	0	0	0	0	152851	8611,620117	226335	89192,43	60482,14	22500	0	0	0	0	
1.12	260 zesde	559972,2		0	0	0	0	0	0	0	0	0	152851	8611,620117	226335	89192,43	60482,14	22500	0	0	0	0	
1.13	270 zeven	559972,2		0	0	0	0	0	0	0	0	0	64378,4	88472,61719	46357,14	193272,4	84509,5	60482,14	22500	0	0	0	
1.14	280 achtst	559972,2		0	0	0	0	0	0	0	0	0	64378,4	88472,61719	9155,85	230473,7	84509,5	60482,14	22500	0	0	0	
1.15	290 negen	559972,2		0	0	0	0	0	0	0	0	0	0	64378,40234	88472,62	41884,22	197745,3	133682,9	33808,77	0	0	0	
1.16	300 tiende	559972,2		0	0	0	0	0	0	0	0	0	0	64378,40234	88472,62	41884,22	197745,3	133682,9	33808,77	0	0	0	
1.17	310 elfde	559972,2		0	0	0	0	0	0	0	0	0	0	0	64378,4	125673,9	4682,93	314764,2	50472,77	0	0	0	
1.18	320 twaalf	559972,2		0	0	0	0	0	0	0	0	0	0	0	64378,4	125673,9	4682,93	314764,2	50472,77	0	0	0	
1.19	330 dertie	559973,2		0	0	0	0	0	0	0	0	0	0	0	0	152851	41884,22	0	282254,8	49173,37	11309,77	22500	
1.20	340 veerti	322737,5		0	0	0	0	0	0	0	0	0	0	0	0	0	133544,4	152725,4	0	36467,77	0	0	
1.21	buitenaanl	194720,8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	194720,8	0	0	0	0	
1.22	testen en	422387		0	0	0	0	0	0	0	0	0	0	0	0	0	0	99385,18	99385,18	223616,6	0	0	
		0																					
Summa																							19429810,5
Total Budgeted Cost		**19429811**		1 018 793 €	297 328 €	720 328 €	########	########	252 653 €	########	20 480 €	507 360 €	########	1 574 932 €	########	########	########	########	598 284 €	346 459 €	11 310 €	22 500 €	
Cumulative Planned Value (PV)				1 018 793 €	########	########	########	########	########	########	########	########	########	10 793 120 €	########	########	########	########	########	########	########	########	
		Delta $_{PV}$		***0 €***	***0 €***	***0 €***	***0 €***	***0 €***	***0 €***	***0 €***	***0 €***	***0 €***	***0 €***	***0 €***	***0 €***	***0 €***	***0 €***	***0 €***	***0 €***	***0 €***	***0 €***	***0 €***	***0 €***
		Delta $_{n-1}$		***xnxx.com***	***#######***	***#######***	***#######***	***#######***	***#######***	***#######***	***#######***	***#######***	***#######***	***19 429 811 €***	***#######***	***#######***	***#######***	***#######***	***#######***	***#######***	***#######***	***#######***	

Figure 2-6. Screen capture of Change Management tab in the EVM Tool

Appendix 3. EVM Tool Graphs



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
PV	1 018	1 316	2 036	3 246	4 256	4 509	6 572	6 592	7 099	9 218	10 793	14 017	15 474	16 907	18 451	19 049	19 396	19 407	19 429	
AC	1 111	1 395	2 475	2 594	3 973	4 507	5 539													
EV	1 009	1 289	2 325	2 442	3 751	4 256	5 249													
BAC	19 429	19 429	19 429	19 429	19 429	19 429	19 429	19 429	19 429	19 429	19 429	19 429	19 429	19 429	19 429	19 429	19 429	19 429	19 429	
AT							1													

Figure 3-1. Earned Value graph in the EVM Tool

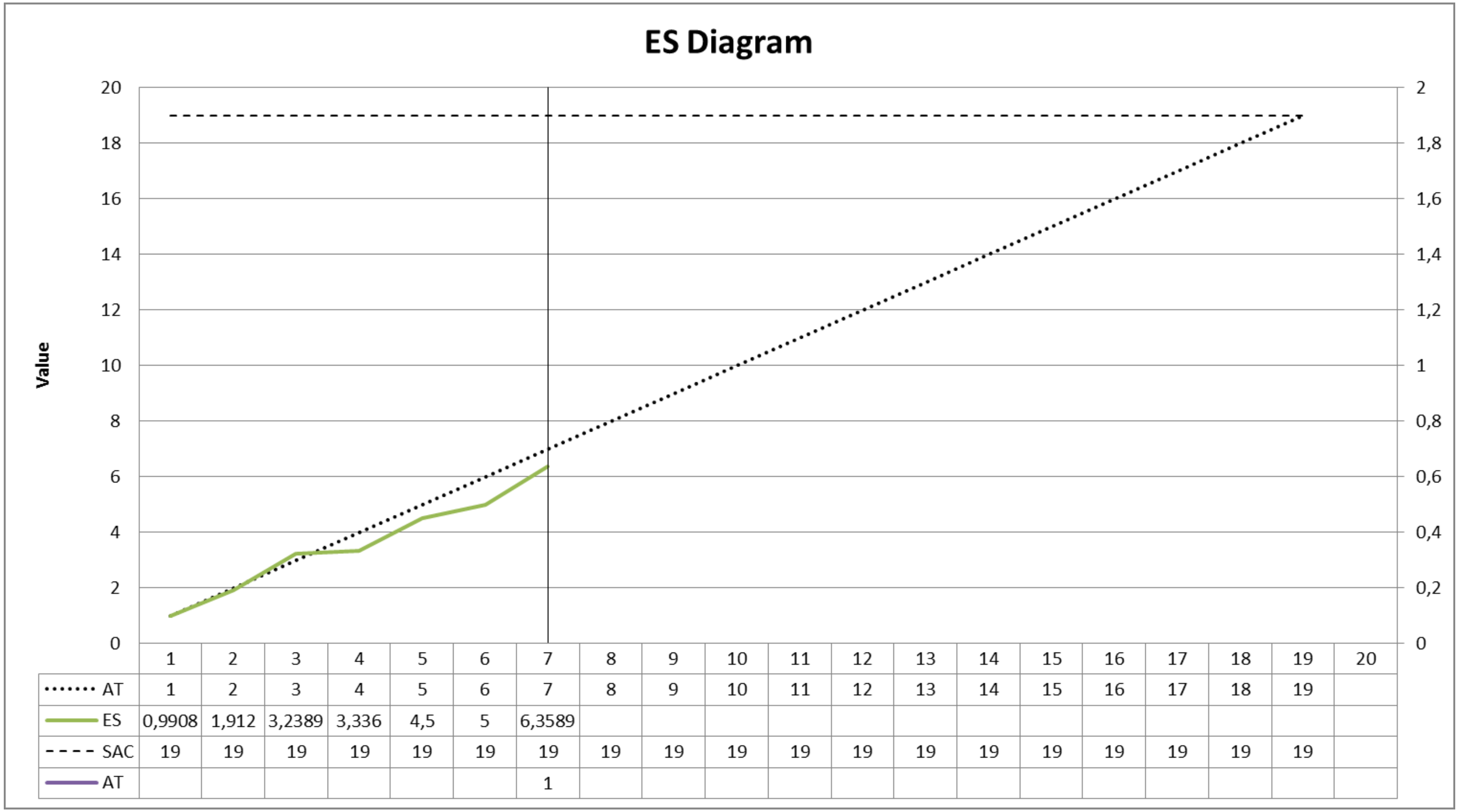
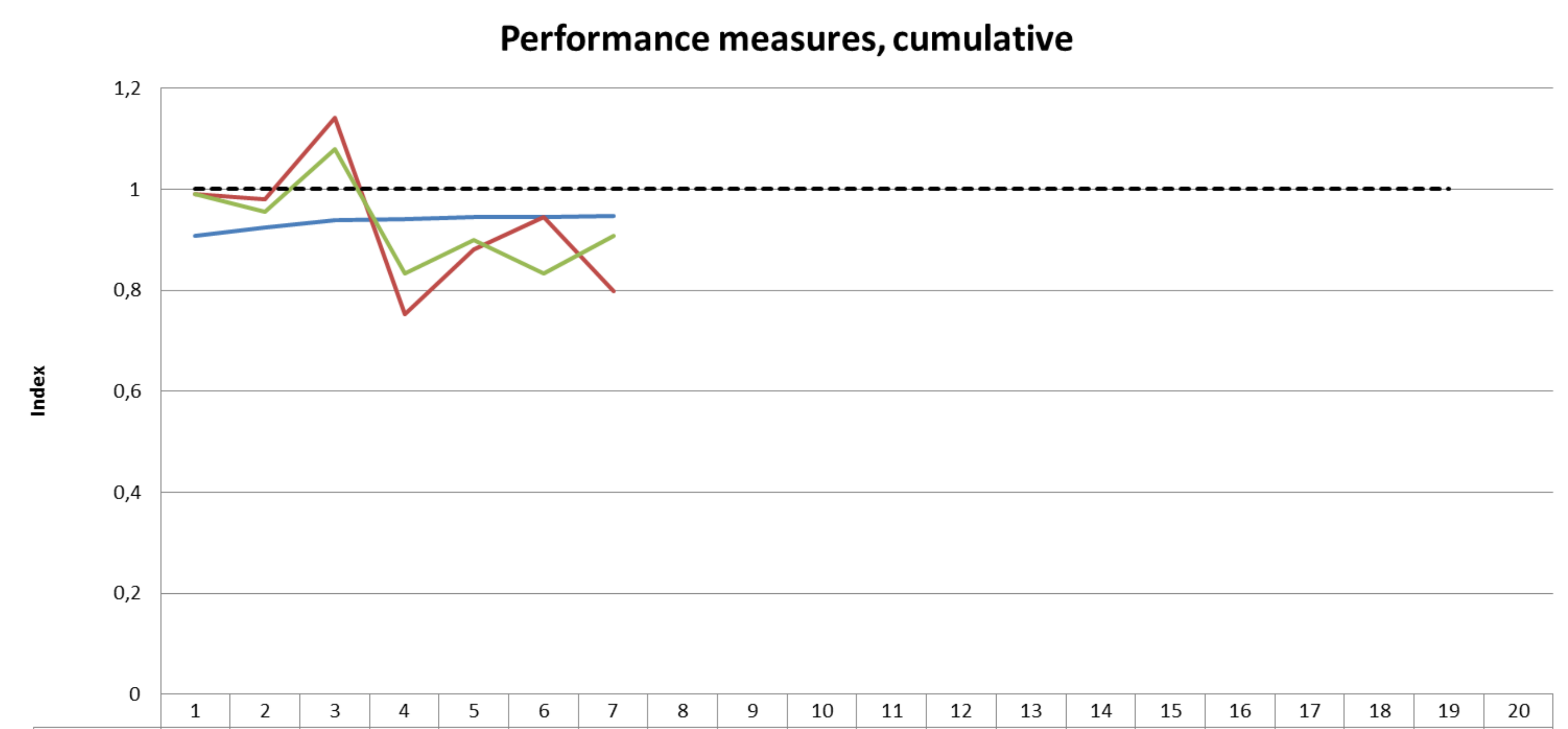
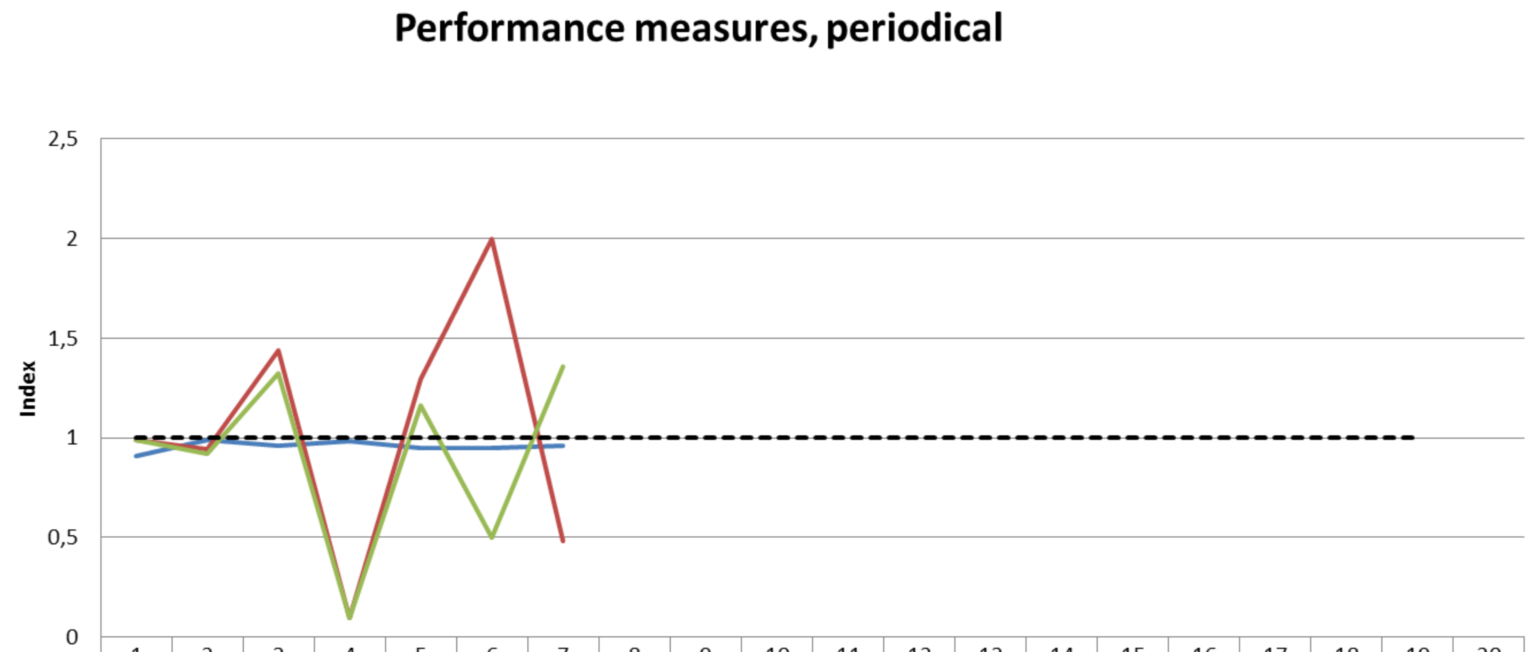


Figure 3-2. Earned Schedule graph in the EVM Tool



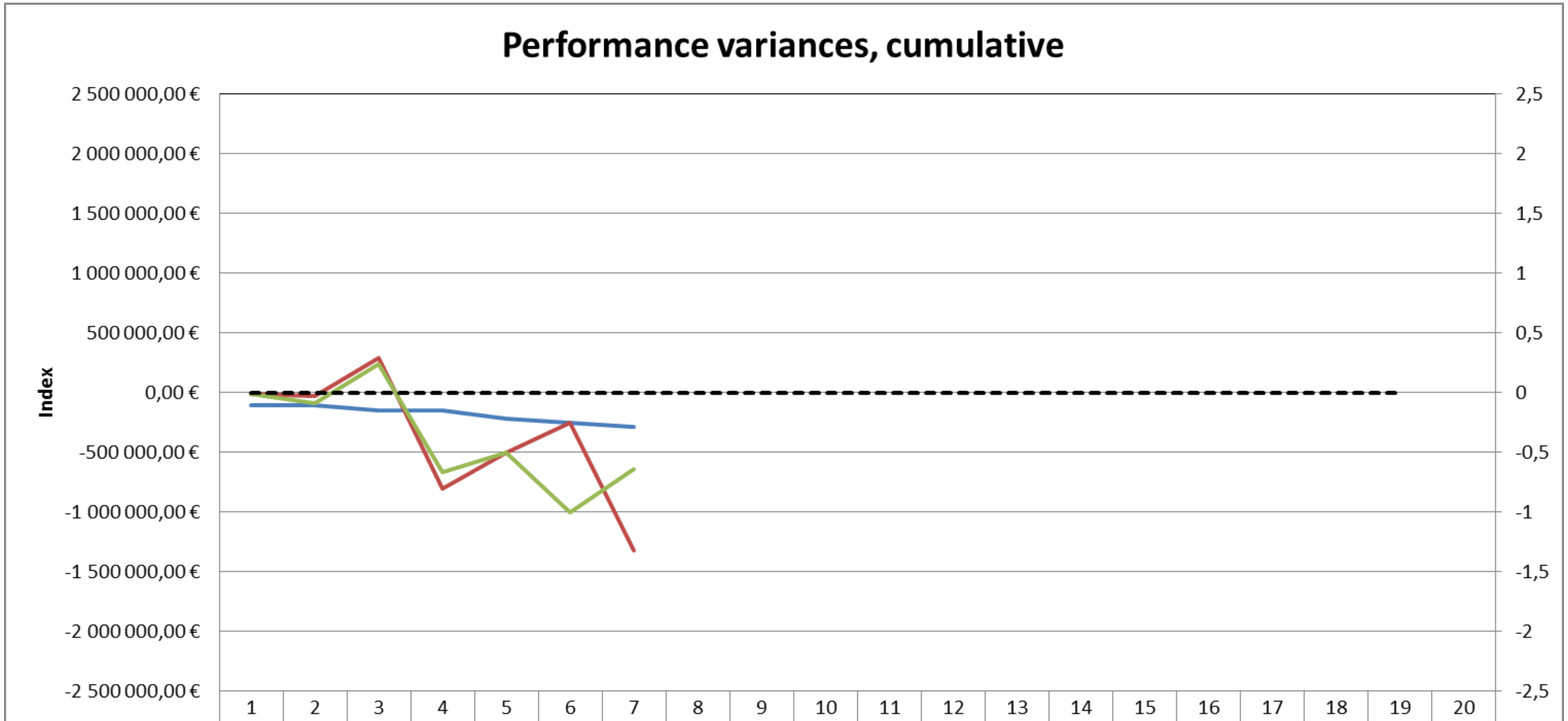
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
CPI	0,9079	0,9242	0,9395	0,9415	0,9441	0,9444	0,9477													
SPI	0,9908	0,9801	1,1419	0,7526	0,8813	0,944	0,7988													
SPI(t)	0,9908	0,956	1,0796	0,834	0,9	0,8333	0,9084													
Basel.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	

Figure 3-3. Graph of cumulative performance measures in the EVM Tool



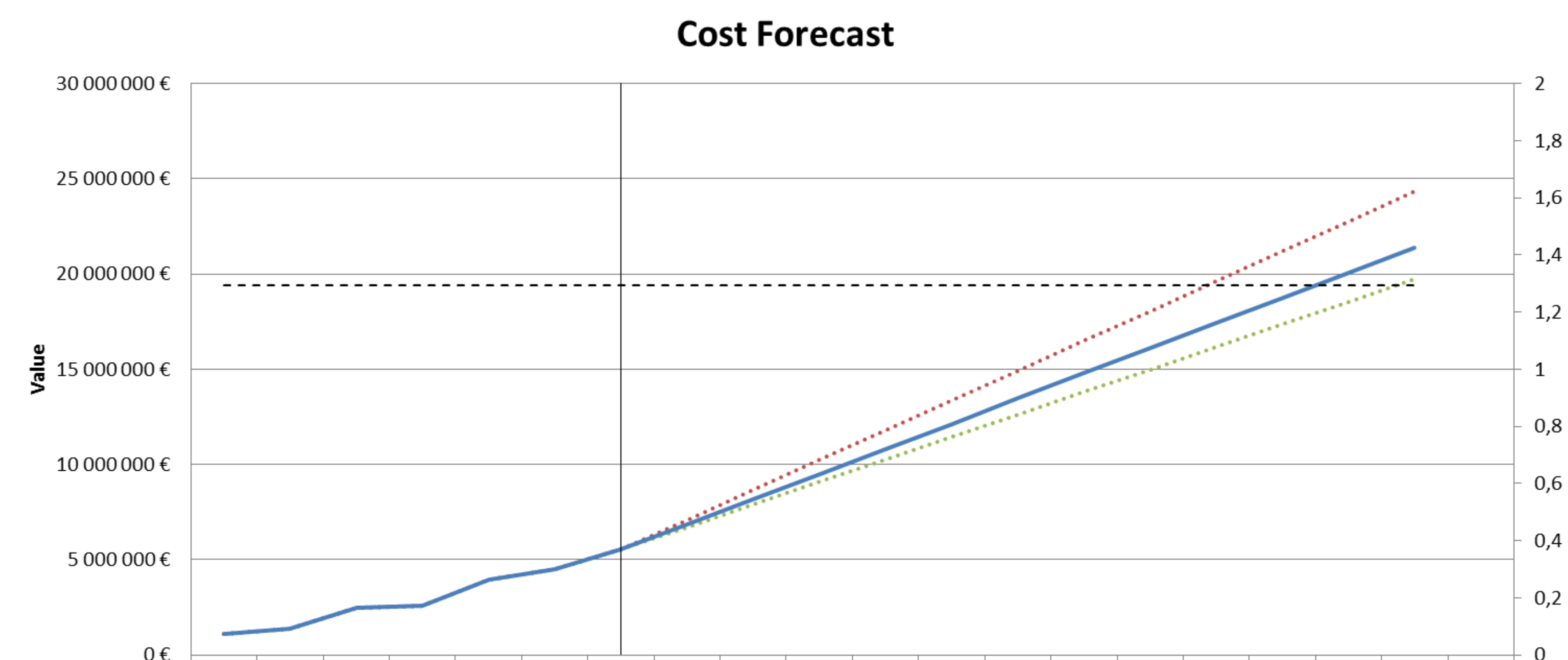
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
CPI	0,908	0,988	0,959	0,983	0,949	0,947	0,962													
SPI	0,991	0,944	1,438	0,097	1,295	2	0,481													
SPI(t)	0,991	0,921	1,327	0,097	1,164	0,5	1,359													
Basel.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	

Figure 3-4. Graph of periodical performance measures in the EVM Tool



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
CV	-102	-105	-149	-151	-222	-250	-289													
SV	-9 39	-26 1	288 9	-803	-505	-252	-1 32													
SV(t)	-0,01	-0,09	0,239	-0,66	-0,5	-1	-0,64													
Basel.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Figure 3-5. Graph of cumulative performance variances in the EVM Tool



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
EAC-min	1 111	1 395	2 475	2 594	3 973	4 507	5 539	6 721	7 902	9 084	10 266	11 447	12 629	13 811	14 992	16 174	17 356	18 537	19 719	
EAC-max	1 111	1 395	2 475	2 594	3 973	4 507	5 539	7 104	8 670	10 235	11 801	13 366	14 932	16 497	18 063	19 628	21 193	22 759	24 324	
EAC-4	1 111	1 395	2 475	2 594	3 973	4 507	5 539	6 860	8 180	9 501	10 822	12 143	13 464	14 784	16 105	17 426	18 747	20 068	21 388	
BAC	19 429	19 429	19 429	19 429	19 429	19 429	19 429	19 429	19 429	19 429	19 429	19 429	19 429	19 429	19 429	19 429	19 429	19 429	19 429	
AT							1													

Figure 3-6. Graph of cost forecasts in the EVM Tool