UNIVERSITEIT GENT

FACULTEIT ECONOMIE EN BEDRIJFSKUNDE

UNIVERSITEIT GENT

FACULTEIT ECONOMIE EN BEDRIJFSKUNDE

ACADEMIEJAAR 2009 – 2010

Performance analysis of Earned Value Management in the construction industry

Masterproef voorgedragen tot het bekomen van de graad van

Master in de Toegepaste Economische Wetenschappen: Handelsingenieur

Pieter Buyse & Tim Vandenbussche

onder leiding van

Prof. Dr. M. Vanhoucke

Permission

Date:

Pieter Buyse | Tim Vandenbussche

Preface

Many people were involved in writing this thesis. That is why we would like to address this part to thank them.

First of all we would like to thank our promoter, Dr. Mario Vanhoucke, for his proper guidance while writing this thesis. His enthusiasm and personal commitment served as one of our main motivations. At the same time did he provide us with the necessary knowledge and insights.

Secondly we would like to thank the different companies we worked with. In particular we would like to thank the following people.

- Bruno De Paepe & Joris Muylaert (Jan De Nul)
- André Boelaert, Glenn Deleter & Filip Vertongen (Strabag)
- Bernard Danhier and Marianne Strydonck (Fluxys)
- Kris De Caluwe (Louis De Waele)
- Koen Muller & Jan Landuyt (Soetaert)

We would really like to thank every one of them for their enthusiasm, patience and time. They provided us with the necessary data and without their cooperation we would have never been able to complete this thesis.

Last but not least we would like to thank our families and friends for their support and input. It was a good motivation for us to know that we could always count on them.

Table of contents

List of Abbreviations

AC=Actual Cost (=ACWP)
ACWP=Actual Cost of Work Performed (=AC)
AD=Actual Duration
AT=Actual Time
BAC=Budgeted Actual Cost
BCWP=Budgeted Cost of Work Performed
BCWS=Budgeted Cost of Work Scheduled
CPI=Cost Performed Index
CPM=Critical Path Method
CR=Critical Ratio (=CSI=SCI)
CR=Cost reimbursable contract
CSI=Cost Schedule Index (=CR=SCI)
CV=Cost Variance
DoD=Department of Defense
EAC=Estimate At Completion (cost)
EAC(t)=Estimate At Completion (date)
ED=Earned Duration
ES=Earned Schedule
ETC=Estimate To Completion (cost) (=PCWR)
ETC(t)=Estimate To Completion (date)
EVM=Earned Value Management
FP=Fixed Price contract
IEAC(t)=Independent Estimate At Completion (date)
P= P-factor
PC=Percentage Completed
PD=Planned Duration
PD(t)=Planned Duration at time t
PM=Project Manager
PF=Performance Factor
PCWR=Planned Cost of Work Remaining (=ETC)
RACI= Responsible, Accountable, Consulted, Informed
RB=Re-Baselined
RM=Risk Management
SCI=Schedule Cost Ratio (=CR=CSI)
SP=Serial-Parallel indicator
SPI=Schedule Performed Index
SPI(t)=Schedule Performance Index at time t
SV =Schedule Variance
SV(t) =Schedule Variance at time t
TCPI=To Complete Performance Index
TV=Time Variance
VM=Value Management
WBS=Work Breakdown Structure

List of Figures and Tables

Introduction

In writing this thesis it was our goal to conduct some interesting research that could be tested against the theory. We found this possibility in the area of project management where our promoter Dr. Mario Vanhoucke already did a lot of research in Earned Value Management (EVM). This methodology was developed to help Project Managers (PMs) in following up their projects and take appropriate action when the project gets out of hand.

This subject caught our specific interest as we noticed the simplicity and effectiveness of EVM in controlling projects. We were really eager to check if this method could also proof useful in a sector where it still had to earn its stripes. Although the construction sector is one of the stereotype sectors when talking about projects, the implementation of EVM has not gone smoothly. Therefore the question was asked by us "if this method would be implemented, would it then provide some added value for PMs and companies in following up their projects?"

When we were looking for real life data we contacted several of the biggest Belgian construction companies together with some smaller ones. Out of the large bunch of contacted companies data was obtained concerning five projects that were already finished. This allowed us to check the effect that the use of EVM could have had on the execution of those five construction projects.

The data and information gathered on those five projects were used to make suggestions toward the implementation of EVM in the construction sector and to check whether similar results could be found in the literature. For analysing the data, the recently developed software package ProTrack was used. The results obtained from analyzing these five projects have no intention of falsifying or validating any theory or whatsoever. Therefore the sample size is too small. It rather aimed at providing an extensive qualitative research where all possible influencing factors were discussed and explained based on our findings.

This thesis is constructed so that readers unfamiliar with EVM can find all necessary basics in the first part before starting with summarizing some of the most interesting findings concerning this method in the second part. The third part focuses on EVM implementation and efficiency in the construction sector and hereby concludes the theoretical part. In part four an introduction is given of our study and the methodology is explained. Because the projects in the sample all have specific characteristics, a project overview is given in part five. The sixth part gives an overview of the results of the research and is followed by an overall conclusion.

1. EVM BASICS

Introduction

The birthplace of Earned Value Management (EVM) is situated within the United States Department of Defence (DoD). In the 1960s the DoD decided that more appropriate control was needed to manage their huge projects and related budgets. More specific it was their intend to obtain early warning signals and predict the outcome of their projects much earlier in the project life.

This was realised by creating a standard method to measure and evaluate a project's performance based on basic measures. Since then EVM has proven to be very valuable as a control system for project managers (PMs) who want to keep track of their projects in a quantitative way. EVM provides an analysis of both the cost and schedule performance of a project. This is done by analyzing on a regular basis the value of the work that was planned, that is really executed and its actual cost. All values are expressed in monetary units, a main characteristic of EVM.

The unique interaction of the three project management elements (scope, cost and time) that is done by EVM provides PMs with crucial information on the performance and progress of their project during its life cycle. This information helps PMs to identify what needs to be done to bring the project back on track, cost and schedule wise. The following section gives an overview of the basics of EVM, based on several books and articles including Anbari (2003), Fleming en Koppelman (2005) and Vanhoucke (2009).

Besides the traditional EVM methods, the section also includes Earned Schedule (ES). This recently developed extension overcomes certain pitfalls of EVM, especially in forecasting duration. The section about ES is based on the article "Schedule is Different" (Lipke, 2003).

EVM Metrics

Key EVM Parameters

For implementing EVM/ES, a clear project scope is required together with a project budget and a project schedule. The project budget must reflect all planned costs incurred by the activities of which the project consists. The budget is then distributed over all the activities in the project schedule. By cumulating these budgeted costs over time a first measure is obtained, the **Planned Value (PV)**. The PV is the value that was planned to have been spent according to the original plan at a certain point in time. The Budget at Completion (BAC) is the total cost of the project as it was budgeted at the start of the project and is equal to the planned value at the end of the project (see figure 1).

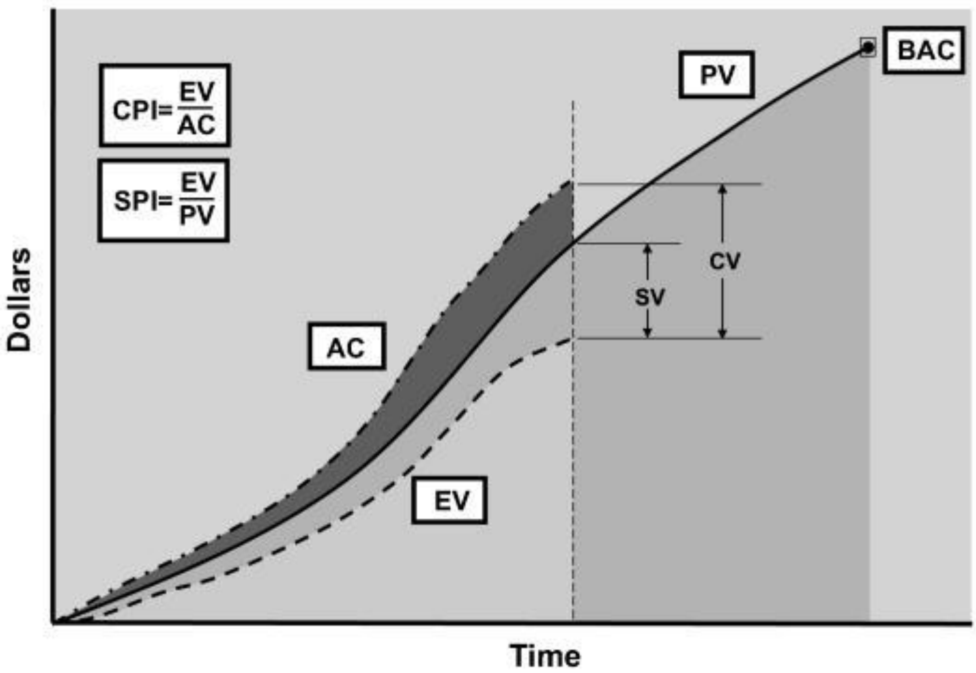


Figure 1: Earned Value Basics (Source: Lipke W., 2003, p.2)

During project execution two more measures are obtained so that a comparison can be made between reality and plan. **Earned Value (EV)** is the monetary value of the activities that are finished at a certain point in time. Another way of putting it, is that the EV equals the BAC multiplied by the percentage completed (PC) at a certain point in time (EV = PC * BAC).

The other measure is the **Actual Cost (AC)**. This represents the real costs for all work that is executed at a certain point in time. As can be seen in figure 1 these measures are also cumulatively represented over time.

Summarized, EVM makes use of **three key parameters**:

- Planned Value (PV) = (BCWS) Budgeted Cost of Work Scheduled
- Earned Value (EV) = (BCWP) Budgeted Cost of Work Performed
- Actual Cost (AC) = (ACWP) Actual Cost of Work Performed

Performance Measures

When the three key parameters are properly recorded along the project life, PMs are able to calculate two types of performance measures. The first type of performance measures are variances which represent the difference between the current status of the project and its baseline, in monetary terms. The **Cost Variance (CV)** is used to follow up the project budget. A negative (positive) value points out that more (less) has been spent for the executed activities than what was originally planned. The **Schedule Variance (SV)** is an indicator that provides PMs with a value that represents whether the project is on schedule or not. A negative (positive) value means that the project is behind (ahead of) schedule. The variances are also shown in figure 1.

The **variances** can be derived as follows:

- Cost Variance: CV = EV – AC
- Schedule Variance: SV = EV – PV

Another type of performance measures are indices, also calculated from the three key parameters of EVM. The indices are again used to display how well the project is performing, now relatively in comparison with the baseline. Again two types of indices can be distinguished. The first type of index is the **Cost Performance Index (CPI)**, which expresses the cost efficiency of the executed work. A CPI of less (more) than one means that the project is currently running over (under) budget. The second index is the **Schedule Performance Index (SPI)**. The SPI shows whether the project is performing on schedule or not. A SPI of more (less) than one means that the project is ahead of (behind) plan.

The **indices** can be derived as follows:

- Cost Performance Index: CPI = EV / AC
- Schedule Performance Index: SPI = EV / PV

It is clear that the variances and indices are interrelated. Still it is useful to calculate both performance measures. The variances can give a snapshot of where the project is today (expressed in monetary value) while the indices are rather used to represent the evolution in performance of the project. This is of significant importance to make forecasts about the future of the project.

Predicting the future with EVM

All of the performance measures help PMs to monitor the progress of the project both from a cost and schedule point of view. Therefore EVM acts as an early warning system that helps PMs to solve problems and exploit opportunities during project execution. Besides, these measures and indicators are also used to make predictions about the future performance of the project. The next section will describe how cost and time forecasts are made using EVM.

Cost forecasting

First of all the predictive power of the cost performance measures is considered. Here the focus lies on predicting the final cost of the project. This final cost will be referred to as the Estimate at Completion (EAC). The EAC consists of the Actual Cost (AC), the cost that has been spent so far and an estimate of the cost of the remaining work (Estimate to Completion, ETC). In some literature, ETC is also referred to as Planned Cost of Work Remaining (PCWR). It can be calculated as follows:

$$\text{ETC} = \frac{(\text{BAC} - \text{EV})}{\text{performance factor}}$$

Several different formulas exist to calculate the EAC, depending on the performance factor that is used to calculate the ETC. In general eight commonly used forecasting formulas are accepted by project managers (see table 1).

$\text{EAC}_1 = \text{AC} + (\text{BAC} - \text{EV})$	$\text{EAC}_5 = \text{AC} + \frac{\text{BAC} - \text{EV}}{\text{CR}}$
$\text{EAC}_2 = \text{AC} + \frac{(\text{BAC} - \text{EV})}{\text{CPI}}$	$\text{EAC}_6 = \text{AC} + \frac{\text{BAC} - \text{EV}}{\text{CR(t)}}$
$\text{EAC}_3 = \text{AC} + \frac{(\text{BAC} - \text{EV})}{\text{SPI}}$	$\text{EAC}_7 = \text{AC} + \frac{\text{BAC} - \text{EV}}{\text{wt1} * \text{SPI} + \text{wt2} * \text{CPI}}$
$\text{EAC}_4 = \text{AC} + \frac{\text{BAC} - \text{EV}}{\text{SPI(t)}}$	$\text{EAC}_8 = \text{AC} + \frac{\text{BAC} - \text{EV}}{\text{wt1} * \text{SPI(t)} + \text{wt2} * \text{CPI}}$

Table 1: EAC formulas

EAC_1 assumes a discount factor that is equal to one. This means that to estimate the remaining cost of the project, no project performance measure is taken into account. The remaining cost is assumed to equal the planned cost for the remaining work. The most commonly used formula for cost forecasting is EAC_2. In this formula the CPI is used as a discount factor for estimating the remaining cost. EAC_3 and EAC_4 on the other hand are used in cases where the duration has a huge impact on the final cost of the project.

In the last four EAC formulas it is supposed that both the cost and schedule performance indicators have an impact on the cost of remaining work. The discount factor in EAC_5 is called the critical ratio (CR) (Anbari, 2001; Lewis, 2001) or cost - schedule index (CSI) (Barr, 1996; Meredith & Mantel, 2000) or schedule - cost index (SCI) (Christensen, 1999; Vanhoucke, 2010). It attempts to combine cost and schedule indicators into one overall project health indicator. A CR equal to one indicates that overall project performance is on target while a lower number indicates less than targeted performance.

CR is derived as follows:

$$CR = CPI * SPI$$

A performance factor equal to the CR(t) substitutes the SPI by the SPI(t). The last two equation EAC_7 and EAC_8 are derivative formulas which give a weight to both the CPI (wt1) and the SPI/SPI(t) (wt1). This way a customized formula can be obtained for the project.

Duration forecasting

EVM has also been used for more than forty years to predict the final duration of projects. This is done analogue to forecasting the EAC. The oldest method calculated the Independent Estimate At Completion (IEAC(t)). This estimate exists of the time that has already elapsed (Actual Time, AT) and the duration of what the remaining work is estimated to take (Estimate To Complete, ETC(t)). The time that is expected to complete the project is calculated by adjusting the work remaining (Estimate To Complete, ETC) for the work rate that is expected on the remaining of the project. ETC(t) is also referred to as Planned Duration of Work Remaining (PDWR) and can be calculated as follows:

$$ETC(t) = \frac{(BAC - EV)}{\text{Work Rate}}$$

The Independent Estimate at Completion (IEAC(t)) can be derived as follows:

$$IEAC(t) = AT + ETC(t)$$

Four commonly applied work rates were used to translate a monetary value into a time value:

Average Planned Value (PVav = PVcum/n)
Average Earned Value (EVav = EVcum/n)
Current period Planned Value (PVlp)
Current period Earned Value (EVlp)

Table 2: Work rates

Although this traditional method was applied for forty years, it deals with certain mathematical deficiencies (for more information see *Lipke (2009), "Project Duration Forecasting."*). This induces that the method doesn't give reliable estimates for all projects and therefore adjusted methods have been developed.

Recently three extensions to EVM were established: the Planned Value method (Anbari, 2003), the Earned Duration method (Jacob, 2003) and the Earned Schedule method (Lipke, 2003). Table 3 provides an overview of the duration forecasting formulas of these three methods. Depending on the discount factor, three forecast formulas can be derived for each method.

Planned value method (Anbari)	**Earned duration method** (Jacob)	**Earned schedule method** (Lipke)
$\text{EAC(t)}_{\text{PV}\,1} = \text{PD} - \text{TV}$	$\text{EAC(t)}_{\text{ED}\,1} = \text{AD} + (\text{PD} - \text{ED})$	$\text{EAC(t)}_{\text{ES}\,1} = \text{AD} + (\text{PD} - \text{ES})$
$\text{EAC(t)}_{\text{PV}\,2} = \frac{\text{PD}}{\text{SPI}}$	$\text{EAC(t)}_{\text{ED}\,2} = \text{AD} + \frac{(\text{PD} - \text{ED})}{\text{SPI}}$	$\text{EAC(t)}_{\text{ES}\,2} = \text{AD} + \frac{(\text{PD} - \text{ES})}{\text{SPI(t)}}$
$\text{EAC(t)}_{\text{PV}\,3} = \frac{\text{PD}}{\text{CR}}$	$\text{EAC(t)}_{\text{ED}\,3} = \text{AD} + \frac{(\text{PD} - \text{ED})}{\text{CR}}$	$\text{EAC(t)}_{\text{ES}\,3} = \text{AD} + \frac{(\text{PD} - \text{ES})}{\text{CR}}$

Table 3: EAC(t) formulas

The **Planned Value method** (PV) relies on the Planned Duration for the entire project (PD), expressed in time units, to make forecasts about the future. This factor is then adjusted to the performance of the project. In $\text{EAC(t)}_{\text{PV1}}$ the adjustment factor is the Time Variance (TV). which can be calculated by dividing the schedule variance by the planned value rate (PVrate), this is the average planned value per time period.

$$\text{TV} = \frac{\text{SV}}{\text{PVrate}} = \frac{\text{SV} * \text{PD}}{\text{BAC}} = \frac{(\text{EV} - \text{PV}) * \text{PD}}{\text{BAC}}$$

For the other two forecasting equations the SPI respectively the CR (=SPI*CPI) are applied as discount factor to adjust the planned duration.

The **Earned Duration method** (ED) introduces a new variable named Earned Duration (ED). This variable can be calculated by multiplying the Actual Duration (AD) with the SPI.

$$\text{ED} = \text{AD} * \text{SPI}$$

The forecasting formulas differ from each other depending on the performance rate that is used as a discount factor. Performance rates equal to one, the SPI and the CR are assumed.

A remark that definitely needs to be made while presenting the different forecasting methods and formulas is the behaviour of the SV and SPI for projects that finish behind schedule. Figure 2 and 3 show the behaviour of the SV and SPI in comparison with the behaviour of the CV and CPI for a project that finished in April 2002 but was planned to finish in January 2002. The cost indicators appear to behave different than the schedule indicators. For the cost indicators a trend can be recognized throughout the entire project while for the schedule indicators a trend is recognized during a long time in the project but at the end it disappears as the SPI goes back to one and the SV becomes zero.

Because of this irregular behaviour of the SV and SPI these metrics lose their managerial value at the end of the project. As the SPI is commonly applied in cost and duration forecasting formulas, attention should be paid to forecasts made late in the project. When the project appears to finish behind schedule, these biased forecasts will give a wrong view on the reality.

This behaviour can be explained by looking at the SV and SPI formulas. These metrics consist of two parameters: EV and PV. As at the end of the project EV always equals the budget at completion (supra, p.3) and thus equals the PV, it is logical that the SPI always returns to one and the SV becomes zero.

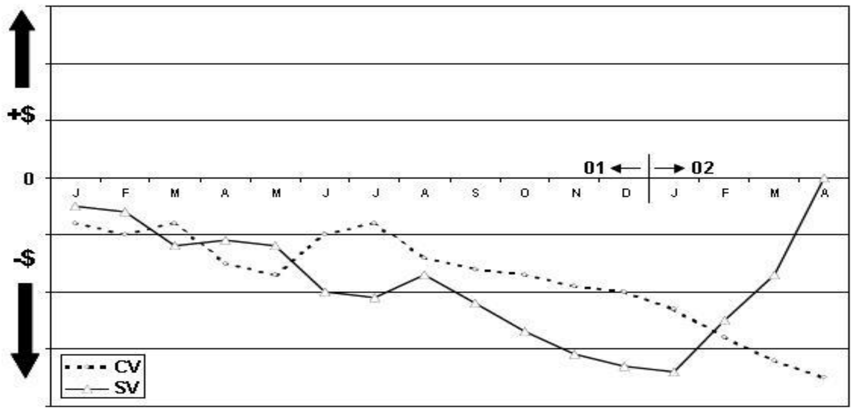


Figure 2: Cost and schedule variances (Source: Lipke W., 2003, p.3)

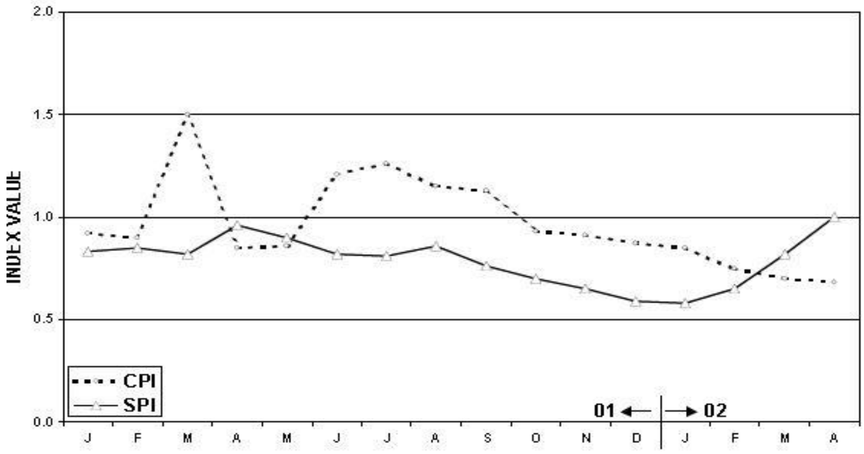


Figure 3: Cost and schedule performance indicators (Source: Lipke W., 2003, p.3)

A method that overcomes this pitfall is Earned Schedule and will be explained more into detail in the following section.

Earned Schedule

The Earned Schedule (ES) method can be seen as an expansion of EVM because the same basic EVM metrics are used and the ES performance measures are similar to those for EVM. ES was first introduced by Lipke (2003) and measures schedule performance in units of time instead of in costs, which is done in EVM. This approach solves the problem that the EVM schedule indicators SV and SPI encounter for late finish projects.

The method is based on two parameters: the Actual Time (AT) and the Earned Schedule (ES). The AT is the duration that has already been spent on the project. The concept of ES is similar to the one of EV in EVM. The value of ES is determined as can be seen in figure 4, by comparing the EV to the schedule (Lipke, 2003). In practice this is done by projecting the EV at a certain point in time (AT) onto the cumulative PV curve. By doing this, a point in time (ES) is obtained at which the current EV should actually have been realized. This can be before or after the current point in time, depending whether the project is behind or ahead of schedule.

With these two parameters, the Schedule Variance (SV(t)) and Schedule Performance Index (SPI(t)) at time t can be calculated. Now these metrics don't need to be translated from monetary units to time units. Similar as in EVM, the ES performance measures can be applied to make forecasts about the final duration of the project. The forecasting formulas are given in table 3.

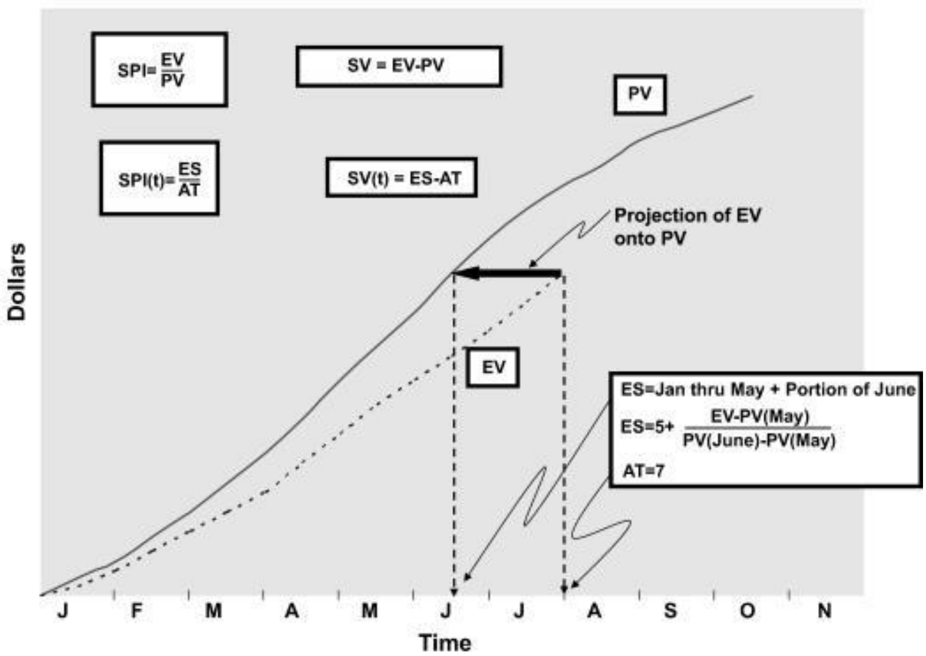


Figure 4: Earned Schedule (Source: Lipke W., 2003, p.5)

P-factor

The P-factor (Lipke, 2004) is a recently proposed Earned Value measure that makes the direct connection between the schedule and EVM data. The P-factor is an indicator for schedule adherence, it measures whether the project is executed according to plan or not. This is important because projects that do not stick to the plan are mostly in trouble or might deal with a higher risk for rework.

For example Project A and Project B have the same PV and EV although they are executed differently. When schedule adherence is not taken into account this will result in similar forecasts for both projects although project B is confronted with a higher risk for possible rework. Adhering to the plan assures that the predecessors to the tasks in progress are completed well and that no rework will be required for these tasks. If however like in project B, certain tasks already started before some predecessors are finished, it might turn out that these tasks have to be redone and so the risk for rework increases.

Project A (high P-factor)　　　　Project B (low P-factor)

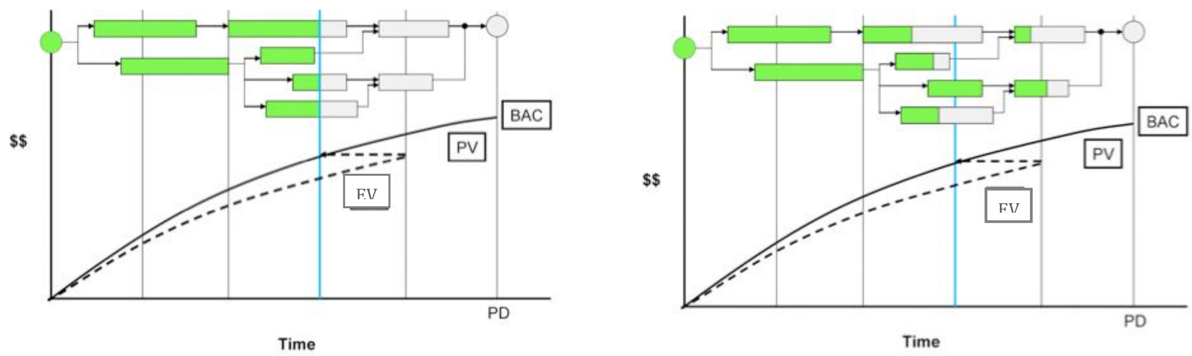


Figure 5: P-factor (Source: Lipke W., 2004, p.4)

The P-factor can be calculated by dividing the earned value corresponding to the baseline schedule at the actual time to the planned value at time ES. The P-factor lies between zero and one as the formula takes the minimum of the planned value at time ES and the earned value accrued to the actual time. For more information can be referred to *Lipke (2004), Connecting Earned Value to the Schedule.*".

$$P = \frac{\sum_{i \in N} \min(PV_{i,ES}, EV_{i,AT})}{\sum_{i \in N} PV_{i,ES}}$$

N: Set of activities in a project

$PV_{i,ES}$: Planned Value of activity i at time instance ES

$EV_{i,AT}$: Earned Value of activity i at the current time AT

Re-baselining

The project baseline is a schedule consisting of all the activities of the project. As certain activities are difficult to forecast at the project start and depend heavily on other activities, the baseline is often established with a lot of uncertainty. During project execution, it might turn out that the original baseline becomes unrealistic as a basis for management control. This can be due to changes in scope, schedule, cost or a combination of these factors. To make the project manageable again, the project baseline can be changed. This is called re-baselining. An example is given in figure 6 and 7:

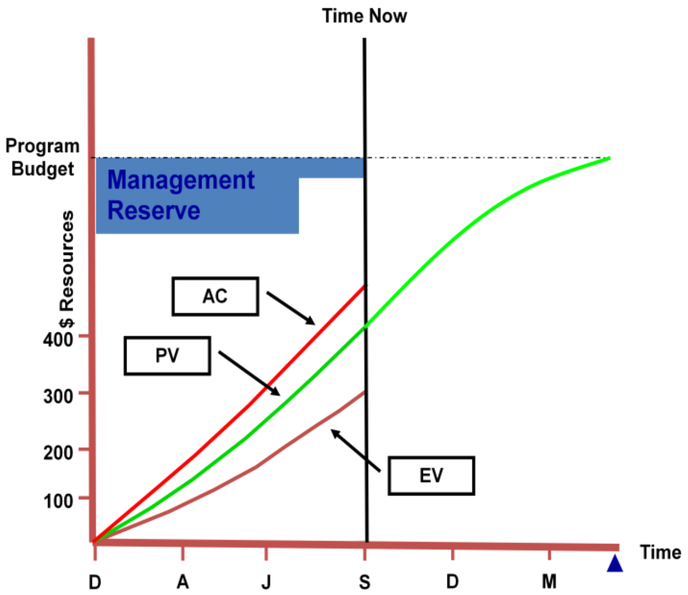


Figure 6: Project with current baseline (Source: Abba, W, 2006)

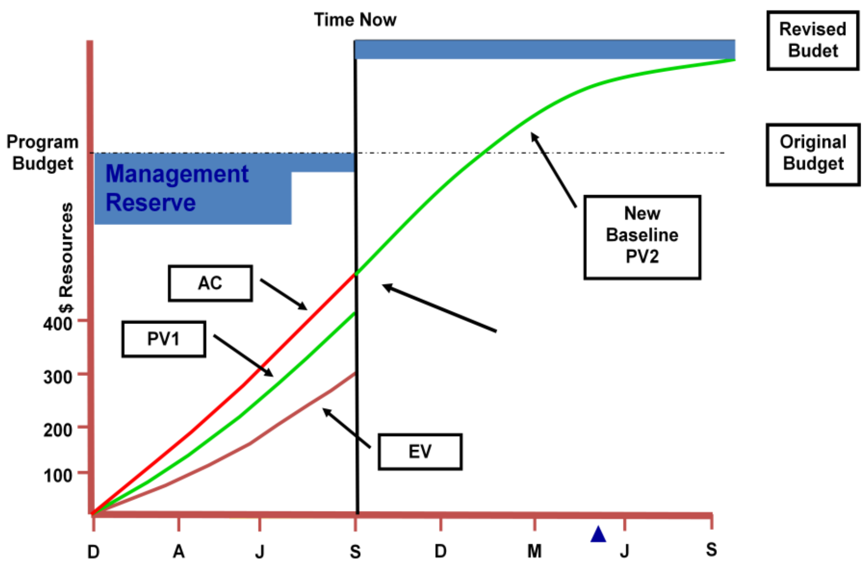


Figure 7: Project re-baselined (Source: Abba, W, 2006)

Starting from figure 6, it can first be seen that there is a persistent trend of the actual cost being higher than the planned value. This explains a cost overrun for the performed work and a budget revision is required. Second the earned value in September (time S) is a lot lower than the planned value at that time. By performing less work than planned the project will be behind schedule and the end date of the project should be revised. Figure 7 shows the re-baselined schedule that continues on the Actual Cost curve (AC) of the project. Start dates, duration and budgeted cost of the different activities are adjusted to the new state of the project which results in a higher budget and longer duration of the project.

The question can be asked when the project baseline becomes so unrealistic that re-baselining is required. Unfortunately there is no clear answer. The balance should be made between on the one hand sticking to the original baseline and making use of forecasting methods that take the original cost and schedule performance into account to make predictions about the future. On the other hand setting up a new baseline restores the cost and schedule variance back to zero. Also the indices are reset to one. This allows future variances to become noticed more easily and will generally result in better forecasts. The negative side is that re-baselining requires extra effort for PMs. The question can therefore be re-established into "is re-baselining worth the effort for PMs to control their project?"

EVM summary

Since its introduction EVM has proven to be very valuable as project management control tool. This because of the different functions it fulfils. EVM provides a view on the current status of the project and also provides insight into the future of the project.

As mentioned before, EVM focuses primarily on the costs of the project, this is why all parameters and measures are expressed in monetary units. On the one hand this enabled EVM to be very good in presenting and analyzing the project's cost performance. On the other hand this led to some anomalies in the schedule performance measures . As noted by Lipke, the expression of the schedule performance measures in monetary units instead of units of time, makes it counterintuitive and difficult to compare with other time based schedule indicators. Another problem incurred by the schedule indicators is that for a project which is behind schedule, at completion SV returns back to zero, and the SPI equals unity. This may lead to biased conclusions about the final duration of the project.

As the implementation of earned schedule overcomes these problems, the credibility of EVM is only rising. Especially with the insertion of the P-factor which closes the gap between schedule and EVM data, EVM can now control projects in a very extended way.

An overview of all EVM key parameters, performance measures and forecasting indicators can be summarized in figure 8, which was found in the book “Measuring Time” by Vanhoucke (2010)

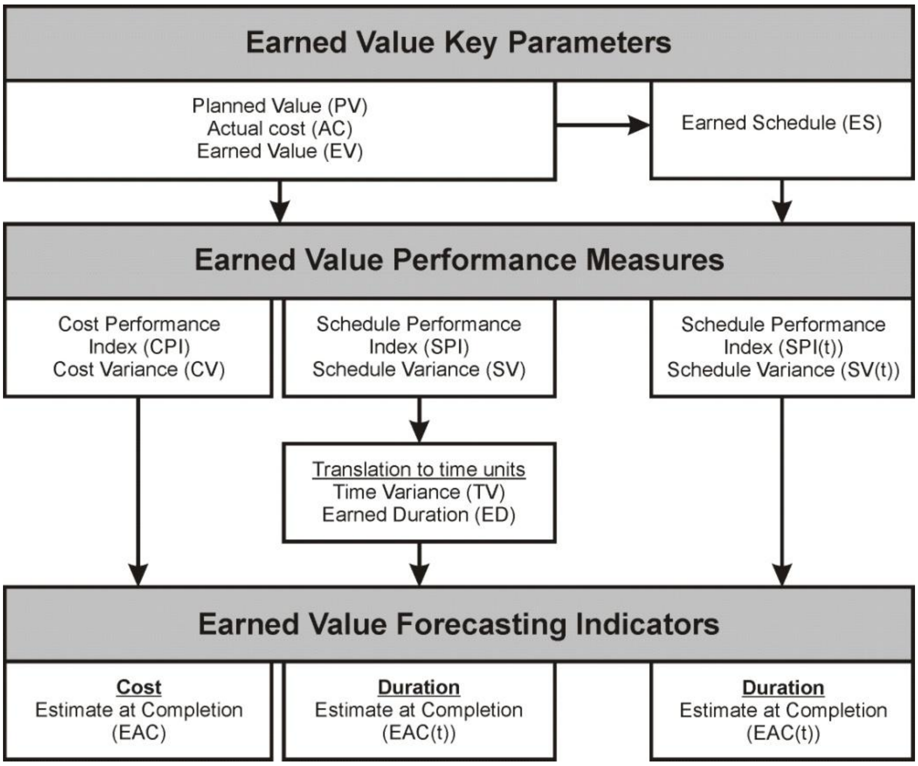


Figure 8: Overview EVM metrics (Source: Vanhoucke Mario, 2010, p.3)

2 EVM studies

During the years, a lot of research has been done in the Earned Value Management domain. This section will give an overview about the most important studies, results and conclusions. The literature will not focus specifically on construction projects but is meant to give a global insight in the use of Earned Value Management in multiple industries. In a later section these findings will be analyzed and criticized in relation to the construction sector. This approach is preferred because currently there is not a lot of specific research available about the performance of the Earned Value Method in the construction sector. First the frequently studied CPI stability findings are presented. Subsequently studies about the different forecasting methods are discussed and re-baselining is considered. To conclude an overview of the influencing project characteristics is given.

CPI stability

A first study object is the stability of the CPI. The CPI is an indicator of the cost performance efficiency of a project and its stability is important for three main reasons (Christensen and Heise, 1993). First, the CPI is a parameter that is used in many EAC formulas which predict the cost at completion. Second, a stable CPI might indicate that cost control is performed well because variances are identified early and corrected in the corresponding period. Third, it can be compared with the To Complete Performance Index (TCPI) and be used as a benchmark. For example if the TCPI is significantly higher than the CPI, efficiency will have to be improved for the remaining work in order to avoid cost overruns.

It was long accepted that the CPI does not change with more than ten percent after a project is fifty percent complete, although it lasted until 1990 before empirical evidence was available. The first study was published by Payne (1990). The study analyzed data of seven completed aircraft programs and tested the hypothesis that the cumulative CPI is stable, meaning to have a maximum deviation of ten percent, from the fifty percent completion point. The results confirmed the hypothesis and further investigation on these projects even showed stability from the twenty percent completion point. Even from the ten percent completion point the CPI was stable, except for one project.

A more extended research was executed three years later (Christensen, Heise, 1993). Now data from 155 defence contracts were investigated. Again the hypothesis was that the CPI is stable from the fifty percent completion point and also sensitivity analysis was done for the forty, thirty, twenty and ten completion point. Next to a larger sample size, this study differs from

Payne's study because both the cumulative and non-cumulative CPI were now calculated. The results were satisfying. From the 155 contracts, 153 had a stable cumulative CPI from the fifty percent completion point which confirmed their hypothesis. Also from the twenty percent completion point, cumulative CPI stability was achieved for a 95 percent confidence interval. Another result of this study was that non-cumulative CPI stability could not be concluded. Non-cumulative CPI stability was tested on three different time intervals: every three months, every six months and with a six months moving average. The results in table 4 show that from the fifty percent completion point for neither of the three measurement methods significant stability was obtained. Only six percent of the contracts had stable three month CPI's, thirty-two percent had stable six month CPI's and nineteen percent had stable six month moving average CPI's. This is an important insight as it makes clear that temporary performance cannot be simply extended to the entire project life. Performance forecasts should be based on performance data over a longer timeframe. Those results also indicate that stability of the cumulative CPI to a large extent is due to the cumulative index which can hide possible CPI fluctuations.

	Three month	**Six month**	**Six month moving average**
Number of contracts	155	155	155
Contracts with stable CPI	10	50	29
Percent stable	6%	32%	19%

Table 4: CPI stability (Source: Lipke W., 2004, p.4)

This research on military projects at the US Department of Defence (DOD) in the early nineties showed evidence of the usefulness of EVM. This attracted many of the pioneers to the domain of Earned Value Management. Four widely published stability findings got generalized to all kinds of projects and are until today used as a rule of thumb for many project managers (Lipke, Zwikael, Henderson, Anbari, 2009):

- EAC = BAC/CPI is a reasonable running estimate of the low value for final cost.
- The cumulative value of CPI stabilizes by the time the project is twenty percent complete. Stability is defined to mean that the final CPI does not vary by more than 10 percent from the value at twenty percent complete (CPI20%).
- The range for final cost is obtainable from the previous finding: EAC = BAC/(CPI20% ± 0.10).
- The value of CPI tends only to worsen from the point of stability until project completion.

Especially Fleming and Koppelman (2000, 2005), two pioneering EVM researchers, wrote some convincing books and articles that further dispersed the idea that CPI stability exists. Although the latter were also a bit sceptic about the correlation of CPI stability and the size of the project. This arose from the fact that all the projects in the DoD research program were extremely large projects. There is a big difference between the timing of measurement between short and long duration projects. For example the twenty percent completion point of a ten year lasting project is after two years, while for a one-year project this is already after 2,4 months.

A first study that investigated this relation reported that the CPI stability after twenty percent completion is only valid for large projects with a very long duration, generally longer than 6,7 years (Lipke, 2005). For smaller, short duration projects (less than two years), the CPI cannot be evaluated as a reliable predictor for the cost at completion early in the project.

While the results of Lipke still accepted CPI stability to some extent, a study that was published three years later completely contradicted those results (Henderson and Zwikael, 2008). The study intended to analyze the correlation between the CPI and SPI(t) and therefore thirty-seven projects were analyzed: twelve Israeli High-Tech projects, twenty UK construction projects and five Australian IT projects. Stability was again achieved when the CPI deviation between the twenty percent completion point until the final completion was maximum ten percent. The results are shown in table 5.

Stability achieved		**Israeli High tech**	**UK Construction**	**Australian IT**	**Composite**
CPI cum	**<20%**	1	2	0	3
	>20%	11	8	4	23
SPI cum	**<20%**	1	3	0	4
	>20%	11	17	5	33
Total number of projects		**12**	**20**	**5**	**37**

Table 5: CPI and SPI stability (Source: Henderson and Zwikael, 2008)

The table shows that before the twenty percent completion point very few CPI and SPI(t) stability was detected. For the majority of the projects this stability was achieved later on in the project. In fact stability is for many of the projects in the sample only achieved when eighty percent of the project was completed. Remarkable is also that for the UK construction projects only eight out of twenty projects eventually achieved CPI stability while in the other industries this relative amount was much higher.

This study of Henderson and Zwikael (2008) also revealed a consistent behaviour between the CPI and SPI(t), which proved the value of the SPI(t) and Earned Schedule as a good method to control project duration.

The question whether CPI stability can be assumed has no clear answer. Some call it a myth and some still believe it is a general rule. The truth will probably lay somewhere in-between and is dependent on the characteristics of the project, for example the length of the project or the industry. In our study, it is our intention to verify CPI stability for the construction sector and to find reasons why it would be applicable on construction projects or why not.

Cost and duration forecasting

The main reason for many project managers to apply EVM on their projects, is because forecasts about cost and duration can be made early in the project. These forecasts, if reliable, are useful for a project manager because then extra resources can be allocated to the project in order to put the project back on track. During the years a lot of different formulas have been set up to provide the best forecasts. Table 6 gives an overview off the most commonly used formulas which were also already explained in the previous section.

Cost	Duration
$EAC_1 = AC + (BAC - EV)$	$IEAC(t) = AT + \frac{(BAC - EV)}{\text{Work Rate}}$
$EAC_2 = AC + \frac{(BAC - EV)}{CPI}$	$EAC(t)_{PV} = \frac{PD}{PF}$
$EAC_3 = AC + \frac{(BAC - EV)}{SPI}$	$EAC(t)_{ED} = AT + \frac{(ED - AT)}{PF}$
$EAC_4 = AC + \frac{(BAC - EV)}{CR}$	$EAC(t)_{ES} = AT + \frac{(PD - ES)}{PF}$
$EAC_5 = AC + \frac{(BAC - EV)}{(wt1 * SPI + wt2 * CPI)}$	

Table 6: Cost and duration forecasting formulas

Through the years a lot of research has been done to find the best **cost** equation to forecast the Estimated At Completion (EAC). EAC_1 is generally accepted as useless because it assumes that the remaining cost will equal the planned cost. EVM should not be used to make such conclusions. EAC_2 is probably the oldest and certainly the most commonly used cost forecasting equation. A study has showed statistically that this EAC_2 formula can be used as a lower bound between the twenty and seventy percent completion point (Christensen and Rees, 2002). As an upper bound for the cost at completion EAC_4 is commonly used, although this is not examined in a study yet. It is based on the fact that projects that fall behind often require more expensive resources (overtime, extra machines) to keep up with the plan. Therefore the SPI is a good correction measure. It should be remarked that the SPI is only a reliable index early in the project. Especially for projects that fall behind (SPI<1) the SPI moves towards one from the sixty percent completion point and always becomes one at completion. Therefore EAC_4 is a good indicator for an upper bound, but only early in the project.

For estimating the **duration** of a project, the traditional IEAC(t) formulas and three generally accepted methods can be found in the literature: Planned Value $EAC(t)_1$, Earned duration $EAC(t)_2$ and Earned schedule $EAC(t)_3$. The Planned Value method (Anbari, 2003) and Earned Duration method (Jacob, 2003) are confronted with similar SPI problems which influence the accuracy of the forecasts for late finish projects (supra, p.8) from the sixty percent completion point. The Earned Schedule method (Lipke, 2003) overcomes this SPI problem.

An extended research on the accuracy of these three methods (Vanhoucke and Vandevoorde, 2007) showed that the Earned Schedule method (ES) outperforms, on average, both the Planned Value (PV) and the Earned Duration method (ED). The outperformance of ES over PV and ED was found in the early, middle and late phase of the project. Further research (Vanhoucke and Vandevoorde, 2008) revealed that the excelling performance of ES only counts under 'normal' conditions, the schedule performance indicators give a reliable estimate of the project progress during the project lifecycle. When the conditions are not 'normal', ES performs worse than the other two methods.

These last findings give a very important insight in project forecasting accuracy. In our study, special attention will be paid on the characteristics of the several construction projects. This way the best forecasting method should be found and the findings will be compared with the two other methods.

A similar study (Lipke, 2009) confirms the ES dominance in duration forecasting methods. The study investigated the forecasting capability of five different methods, four EVM methods (four IEAC(t) formulas with different work rates) and the ES method. Therefore a sample of sixteen projects consisting of twelve high-tech projects and four IT projects was examined. Using a Sign test with a significance of five percent, it was shown that the ES method outperformed all four EVM methods on every percent completion state of the project.

Re-baselining

Re-baselining the cost and schedule estimates is desirable when the original baseline is no longer viable (Solanki, 2009). The baseline becomes unviable when the result of cost, schedule or technical issues made it unrealistic. These issues can be triggered by either a change of plans or by a performance level that is not in accordance with what was assumed at project initiation. In the article 'An Earned Value tutorial' by Durrenberger (2003) a list of guidelines is given to help project managers decide whether to re-baseline or not.

- The project is out of money
- The project is out of time
- The project is out of resources
- The project stakeholders approve a scope change

To give an answer to the question whether or not to re-baseline the following quote is cited. "Re-baselining is only legitimate when it is performed in response to a stakeholder- approved scope change." (Durrenberger, 2003, p.10)

Characteristics of a project

A project is by definition unique and has different characteristics. Therefore an enormous variety in projects exists. Some projects are rather similar while others will be completely different. This logically implies that not for every project the same EVM technique will give the best result and that EVM is even not appropriate for certain projects. In this section four project characteristics are discussed more into detail in order to create a better understanding of their influence on the use of EVM.

Contract type

A first characteristic is the contract type. In general two basic contract types exist: a **fixed price contract** and a **cost reimbursable contract**. It was always believed that EVM was only useful for cost reimbursable contracts and that for fixed price contracts EVM was rather useless. The last decade however, this point of view has been criticized and nowadays a more mixed belief on contract selection exists.

The traditional point of view was established by large US government departments. They made the first large EVM studies in the Department of Defence (DoD) (supra, p.14) and because of this their influence was huge. Besides the DoD, the National Aeronautics and Space Administration (NASA) also shared the belief that EVM was only required for large cost reimbursable contracts.

The last decade a lot of evidence has been found to reject this traditional point of view and generalize it to include also fixed price contracts. First of all, several anecdotes went around about successful implementation of EVM on fixed price contracts. Later on this revolutionary insight was also accepted by Fleming and Koppelman (2002), two convincing pioneers in the Earned Value domain. Furthermore a method to transform fixed price data into key EVM parameters was discovered (Alvorado et al., 2004). When also Marshall (2005, 2007), one of the main investigators in this domain published his preference to include EVM on fixed price contracts, many project managers were convinced.. Although still some proponents exist, nowadays contract type is mostly considered not to have a huge impact on the choice whether to apply EVM or not.

Length of the project

A second characteristic that was heavily discussed during the years is the length of the project. It has gone through a similar process as the contract type discussion. In the early years of EVM it was considered that EVM was only worth to be used on very long (> five years) projects. The main reason is already discussed before: stability at the twenty percent completion point is only achieved in projects with a long duration. This way the CPI and SPI at the twenty percent completion point can be used to make accurate forecasts about the total cost and duration from early on in the project. This statement was again initiated by the influencing US government departments in the early nineties and is still considered to be correct by some project managers.

However during the last years, more and more project managers started to believe that EVM could also be a good technique for small and medium sized projects. This belief is only appropriate if some rules are taken into account. First it is interesting to increase the reporting cycle from months to weeks or even days for very small projects. Secondly it might be hard and expensive to calculate the actual cost on a daily basis. Then the compromise can be made to adjust the actual costs for example on a weekly basis while adjusting the schedule on a daily basis. Besides a study on projects with a cost of around $200.000 and length of only six months revealed that EVM was very beneficial to these projects (Custers, 2008).

Another finding concerning the duration of projects is that often projects get stuck at ninety percent completion. The last ten percent takes much longer than expected and costs much more than ten percent of the budget. This behaviour is called the ’90 percent syndrome’ and can be found across different types of projects and industries. This symptom can be explained by a common archetype from System Dynamics known as ‘Shifting the Burden’ (Winston and Maroulis, 1998). This relates to the time when activities are completed. Executing activities before they are scheduled can create rework later on in the project life and may be accumulated until the end of the project. This then causes the last ten percent to take ages. This can be seen as one of the main reasons why the p-factor (supra, p.8) is useful in following up a project.

Budget

Projects are also characterized by a budget that is allocated to them. Although the influence of the budget is less crucial to the usefulness of EVM than that of the duration, it is also heavily discussed. Here the size of the budget itself doesn't have an influence on the efficiency of EVM but managers don't think it is worthwhile to apply EVM on projects with a limited budget. This prejudice is prompted by three underlying thoughts.

First of all, many project managers and people in general have the idea that EVM creates a lot of extra work which costs money. But actually most EVM key parameters already exist on most projects. The issue is just to find a common ground between the schedule and cost estimates of a project. For construction projects this connection is present in the public tender that is submitted by the company but afterwards this connection is neglected. This issue is treated more in detail in the section about *'Managing construction projects with EVM'* (infra, p.23).

Secondly there is the fear of having to change the organization of the company or project team when implementing EVM. This could require serious investments if it was really necessary. But this is not the case. EVM just requires that the functional organisational units within the company, which have a certain responsibility over the project, also show up on the project organisation chart.

A last thing that managers think will raise the costs of the project when implementing EVM is the need for a new software package. Most of the time these software packages are pretty expensive but such packages can be useful for large projects but are definitely not necessary. The straightforward calculations that are used by EVM can be easily done in Microsoft Excel.

Network structure

A fourth indicator that was only recently investigated is the influence of the network structure. A first publication (Lipke, 2004) described the importance of schedule adherence, measured by the **P-factor**: an indicator that measures how the schedule is being accomplished according to plan. The P-factor is used as an important early warning signal next to the CPI and SPI(t) because the CPI and SPI(t) say nothing about whether the project is executed according to plan or not.

For this recently applied indicator no empirical evidence about its value is available yet. Although Lipke says that "when P is a high value, we can expect CPI and SPI(t) to be high as well". This statement is formulated by Lipke (2009) but requires further research to be verified.

Another study (Vanhoucke and Vandevoorde, 2009) found a second important network indicator that should be taken into account when applying EVM: the **serial/parallel indicator (SP)**. The main conclusion was that the more the network approaches a serial configuration, the better the forecast estimates become. In a serial network the activity criticality is very high and when one activity is delayed, the complete project will be delayed. This makes the network very predictable. In a more parallel network on the other hand, a delay in a certain task does not automatically leads to a delay in the total project because most of the tasks are not critical and have a certain flexibility. This makes accurate forecasting a lot more difficult.

3 EVM in the construction Sector

Now that the EVM methods have been discussed and that factors influencing the usefulness of these method have been highlighted, it is time to take a more in depth view on the use of EVM in the construction sector. Although this sector was one of the first to commercially adopt the use of EVM, its inherent dynamic nature doesn't make it easy on project managers (Prentice 2003).

To start, some general ideas about the implementation and usefulness of EVM in practice will be discussed. Then the factors influencing the usefulness of EVM that have been discussed earlier will be looked at from the point of view of construction projects. Finally a real life study will be discussed to get an idea of the effect that several factors can have on EVM effectiveness in the construction industry.

Managing construction projects with EVM

The problem of implementing EVM

"If EVM is so good, …why isn't EVM used on all projects?" is the title of an article by the EVM guru's Fleming and Koppelman (2004) and can be considered – ignoring the first part - as the problem definition of this section. Although this thesis only focuses on construction projects, the problems encountered when trying to implement EVM are similar to those encountered on other type of projects. This problem description can then be further divided in two parts. The first part looks for external causes of this problem, without questioning the method itself. The second part approaches the problem from the opposite direction and looks for causes in the EVM method itself. Fleming and Koppelman (2004) found three main reasons why EVM isn't used on all projects and these will be referred to in the following two parts.

- Reason 1: because EVM advocates often speak in a foreign tongue
- Reason 2: because initially the DOD defined EVM to acquire "major systems"
- Reason 3: because sometimes management...doesn't really want to know the full cost!

External causes

Starting with the external causes for not applying the EVM methodology leads to the world of project managers where multiple project control methods exist that help perform project audits and performance assessments. These methods are the same as the ones every effective project manager should have at his disposal (Caletka, 2009), including:

- CPM – Critical Path Method Scheduling
- WBS – Work Breakdown Structure
- EVM – Earned Value Management
- VM/RM – Value Management / Risk Management

All of these methods have proven their usefulness in the area of project management but when taking a closer look at the perception of project managers towards EVM, some **scepticism** is encountered. Opinions like 'EVM is only useful on large, Long-Term projects' and 'EVM does nothing for construction projects' are still floating around. This occurs nevertheless the unremitting effort of several authors who try to dispel these views (Fleming and Koppelman, 2002; Kim et al., 2003; Marshall, 2005; Custer, 2009). The studies performed by those authors all point in the direction of increasing acceptance of the EVM methodology by those project managers who have used and are using EVM.

Another external cause is the **unwillingness to know the full cost of the project beforehand** (Reason 3). This attitude can have several underlying reasons, for more information can be referred to the article by Fleming and Koppelman (2004), *"If EVM is so good, ... why isn't it used on all projects?"*. Sound thinking immediately dispels this so called reason. Every project manager knows this rule: "Bad news never gets better with time." (Fleming and Koppelman, 2002, p.1).

Internal causes

Although EVM is the only methodology that combines measurements of actual, schedule and cost performance in one measurement system, it could equally well be that the reluctance of implementing it can be found in the method itself. Is EVM inherently difficult to implement in the construction sector? Implementing EVM increases the administrative effort of the project management team. If you are new to Earned Value Management and you have read the first section of this thesis on the EVM basics you probably noticed that the **terminology** used by the EVM methods differs quite a lot from the daily language used by project managers on construction projects (Reason 1). This new terminology increases the switching costs of a project manager wanting to implement EVM.

The first section of this thesis contained another pointer why EVM is not used on every project. This time the reason relates to the birthplace of EVM (Reason 2). The Department of Defence (DOD) developed the EVM methodology with the **purpose** of managing major projects with huge budgets. Those are not the projects that are most common in the construction sector. Construction projects are generally characterized by significant smaller budgets and shorter project lives.

<u>Solving the problem</u>

Although these inherent barriers exist, many authors believe that for each of them the advantages of implementing EVM outweigh the efforts needed for EVM implementation (see table 7).

Taking a closer look at the language barrier that EVM entails, mention should be made of the fact that this should be fairly easy to overcome. Even though in the beginning the new terminology may be quite confusing, this obstacle can be overcome by **training and practice**.

To account for projects with a shorter duration than those for which the EVM methodology was developed, an easy solution is that of **more frequently following up** the project. Smaller budgets do not directly influence the usefulness of the EVM methodology, so no solution is needed here.

Problems of EVM implementation	**Proposed Solutions**
External causes	
Scepticism	- (wait and see)
Unwillingness to know full cost in advance	Ability to influence project execution
Internal causes	
Administrative effort	Atomisation
Terminology	Training and practice
Original purpose (big, long-term projects)	Shorter follow-up periods

Table 7: Problems of EVM implementation

Interesting is that in most construction projects managers don't realize that they already have most reporting systems in place to provide the needed data and measurements required by EVM. They just don't use the same terminology. This can significantly reduce the administrative effort required when implementing EVM. If the project managers understand where to look for the data required, an **automated system** could do the trick.

The processes managers of construction projects go through to establish baseline plans and measure performance against their plans, is exactly the same as done in EVM (Fleming and Koppelman, 2002). The project baseline of a construction project is nothing else than the Planned Value (PV). This first step of determining the baseline is crucial to the further effectiveness of EVM measurement. At the same time most managers have a good view on the physical progress of the project. This physical evolution can be easily translated into the Earned Value (EV) of the project. If the Project Manager knows the percentage completed (PC) of each activity at a certain point in time the EV can be derived as can be seen in figure 9.

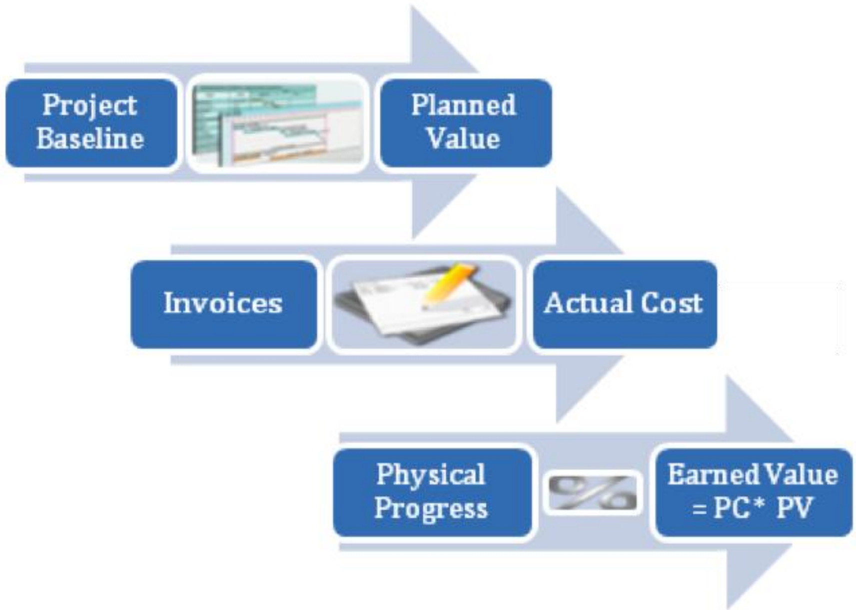


Figure 9: Transforming data into EVM parameters

Determining the Actual Cost (AC) at time t shouldn't be that big a hurdle either but still requires some more effort than deriving the PV and the EV. Those parameters (PV and EV) can be derived for each construction project in an analogous way. Obtaining the AC on the other hand depends on the type of contract (Fleming and Koppelman, 2002) and requires a good reporting system on the use of resources. The project manager must therefore have knowledge about the allocation of the resources over the different activities. Taking into account possible changes in the amount of resources used and price changes, the project manager should be able to compute the actual cost. To do this it is a good idea to start from the invoices because they include the most recent prices. The difficulty here is that although invoices may be the most accurate source for price information, they do not represent the actual amounts of resources used. Therefore project managers should make registration of the team's effort and used resources on this part of the EVM implementation. The best practice here is to find overlap between the Organizational Breakdown Structure (OBS) and the Work Breakdown Structure (WBS) to allocate this responsibility. When this is done the Actual Cost of the current state of the project is known.

For the last couple of years an evolution took place in how project managers perceive the above mentioned problems. Nowadays most of these problems are perceived as "minor" to "insignificant". Today the main problems encountered when implementing EVM are situated in the organizational and cultural domain (Kim et al., 2003). This evolution is the result of the efforts that have been put into improving the EVM processes and the increasing number of testimonials of EVM practitioners. The organizational and cultural problems can be reduced by clearly assigning responsibilities and by increasing the acceptance of the use of EVM throughout the project team. The process of assigning responsibilities can be facilitated by creating a Responsibility assignment matrix or RACI chart to assign responsibilities to persons or organizations involved in the project (Valle and Soares, 2008). Increasing acceptance on the other hand can be achieved by using a top-down approach which states that top management truly believes in the EVM methodology.

Construction project characteristics

To put things into perspective with our study, an overview of the construction project characteristics is presented in this section. Previously mentioned characteristics of projects in general will be recapitulated and discussed from the viewpoint of construction projects. Besides some specific characteristics of construction project will be presented.

Contract type

Having either a fixed price contract or a cost reimbursable contract is crucial to project execution. When a contractor engages in a **fixed price contract** he has to make sure that all future costs are taken into account in the baseline. For these contracts the possibility exists of filing claims as additional expenses were required, but this is still at a risk. For **cost reimbursable contracts** on the other hand the project owner is charged for all costs, shifting the risk to the other side. So the type of contract directly influences the risk associated with the execution. In the construction industry the most frequently applied contract type is the fixed price contract (Fleming and Koppelman, 2002).

Length of the project

The time it takes to execute a project is another general characteristic of a project. In the construction sector this can vary from **several months to a couple of years**. The longer the duration of the project, the higher certain risks such as the ones related to the foreign exchange rate or material prices become (Antvik, 1998).

Budget

Another general project characteristic is the budget. Every project has an according budget that is available to the project organization to complete the project. The budget together with the length of the project and the quality are the key performance indicators for every project in the construction sector.

Network structure

As mentioned before, there are roughly two types of network structures (serial and parallel). In the construction sector the most common network structure is the **serial** one. This is evident because in the construction sector most projects start with the foundation and end by craftsman finishing up the details.

While the previous characteristics were more general, the following characteristics are specific to construction projects. This does not mean that these are not important on other types of projects but it rather means that their importance was of less concern in the previous part treating the findings of EVM related to project characteristics (supra, p.19).

Construction type

The first one of those characteristics is the type of construction. In general, there are three types of construction projects:

1. Building construction
2. Heavy / civil construction
3. Industrial construction

Building construction is the most frequently executed construction type. It generally concerns the construction and renovation of houses and other small buildings. Larger construction projects like bridges, roads, canals, dams and huge buildings fall under the heavy/civil construction type. These projects are also considered to create value for citizens. Finally industrial construction projects include projects for large companies in for example the petroleum, chemical, power generation or manufacturing industry and are rather aimed to make profit.

Type of client

A second characteristic concerns the type of project owner. In the construction sector a clear distinction can be made between three types of construction owners:

1. Public
2. Private
3. Mixed

Although it might be interesting to make a distinction between the projects based on the type of client, evidence was found that accepted the EVM methodology in both the public and private sectors (Kim et al., 2003).

Importance of the project

Every contractor has a portfolio of projects that are executed simultaneously. To prioritize between these running projects the contractor is inclined to make the most important projects perform best. This can be related to reputation, relationship between contractor and project owner or other incentives. So this importance of the project can have a significant influence on its performance.

Bidding environment

Most of the contracts that are related to construction projects have gone through some evaluation and selection criteria. These criteria can also have an influence on the execution of the project. The same can be said for the number of bidders, which were initially competing for the contract. The most common approach toward project approval is the Design-Bid-Build concept. In this approach first a design is approved by an architectural or design firm. Next the different construction companies can make a bid for that design and mostly the company with the lowest bid can execute the contract (Fleming & Koppelman, 2002).

Additional Work

The occurrence of additional work is common in the construction sector and can have a huge influence on the eventual cost and duration. Because additional work is triggered by unforeseeable changes made to the original plan, the project organization is mostly compensated for it by the project owner. When additional work has to be executed, it is common that the project suffers a delay and overruns the budget related to the original plan. This would lead project managers to wrongly judge the performance of the project. Here re-baselining can be appropriate to make sure that EVM performance measures represent the reality instead of comparing actual cost and duration data (including additional works) to the original baseline.

Findings of EVM in the construction sector

To conclude, a real life study where EVM was used to follow up on a construction project is discussed. In this study, mention has been made of some of the factors that are involved when implementing EVM on construction projects. As they see it, "A major problem lies in the determination of an appropriate accounting system to deal with scope changes."(Valle & Soares, 2008, p.2) According to this study an appropriate Work Breakdown Structure together with a suitable accounting plan could solve this problem. This is needed because a scope change can have far stretching consequences for the total project. Not only the schedule and costs of the project are affected by a scope change. resource allocation, milestones, etc. can be compromised as well. Another study that interviewed Project Managers emphasized the influence a clearly defined scope has on the cost-benefit ratio of influencing EVM (Vargas, 2003).

To make everything manageable Valle and Soares (2008) propose to isolate and control in detail those activities with the greatest potential of having an impact on the project. This is an application of Pareto's law which states that only twenty percent of the activities determine eighty percent of the outcome of a project. So by carefully following up on that percentile of the activities with the highest impact on the outcome, the project becomes easier to manage while keeping control over the project.

Another finding about the effectiveness of EVM on construction projects or projects in general is related to responsibilities. The Project Management team should make sure that clear responsibilities exist for each work package (Valle & Soares, 2008). This can be assured by using a Responsibility assignment matrix (RACI chart). This tool combined with the WBS will help project managers in following up projects accordingly.

4 Research

Introduction

This study aims to explore the performance of the Earned Value Method in the construction industry. As mentioned before - although this is based on very little empirical research - it is generally perceived that EVM and construction projects don't fit together really well. A first study (Henderson, Zwikael, 2008) on twenty UK construction projects showed that the generally accepted CPI stability at twenty percent completion only applied for two projects. For twelve projects even no CPI stability was found at all. A second study (Vargas, 2009) investigated the impact of different construction project characteristics to the successful or unsuccessful implementation of EVM. The results showed that EVM is a powerful tool in the control of performance evaluation but only when the scope of the project is very well defined.

This study first aims at giving an overview of the indices stability. The CPI, SPI and SPI(t) are included in the tests. Secondly the different EVM forecasting methods, both cost and time related, are tested on their predictive power. Thirdly, an answer is sought on the question whether re-baselining is worth the effort for construction projects. Finally, special attention is paid on the in the influence of certain project characteristics. The P-factor, SP indicator, length of the project and contract type are included.

Concluding the hypothesises of this study can be formulated in four general questions:

1. **Is EVM a valuable method for following-up construction projects?**
2. **Which EVM forecasting methods perform generally best for construction projects?**
3. **When is re-baselining worth the effort in the construction industry?**
4. **What is the influence of project characteristics on the performance of EVM?**

In this study five construction projects were examined into detail. As this sample size is small, the results should be interpreted with care and generalizations cannot be made. Nevertheless the value of this research lies in the combination of statistical tests with an in depth qualitative research that aims to explain the results. This should allow the reader to get a better understanding of EVM in all its aspects.

Methodology

Variables:

PV=Planned Value
EV= Earned Value
AC= Actual Cost
CPI= Cost Performance Index
SPI= Schedule Performance Index
SPI(t)=Schedule Performance Index at time t
CV=Cost Variance
SV=Schedule Variance
SV(t)=Schedule Variance at time t
EAC=Estimate At Completion (cost)
EAC(t)=Estimate At Completion (date)
BAC=Budgeted Actual Cost
P= P-factor
SP=Serial-Parallel indicator
PD=Planned Duration
PD(t)=Planned duration at time t
AT=Actual Time
ED=Earned Duration
AD=Actual Duration
ES=Earned Schedule

Equations

Cost forecasting

$EAC_1 = AC + (BAC - EV)$	$EAC_5 = AC + \frac{BAC - EV}{CR}$
$EAC_2 = AC + \frac{(BAC - EV)}{CPI}$	$EAC_6 = AC + \frac{BAC - EV}{CR(t)}$
$EAC_3 = AC + \frac{(BAC - EV)}{SPI}$	$EAC_7 = AC + \frac{BAC - EV}{0{,}2 * SPI + 0{,}8 * CPI}$
$EAC_4 = AC + \frac{BAC - EV}{SPI(t)}$	$EAC_8 = AC + \frac{BAC - EV}{0{,}2 * SPI(t) + 0{,}8 * CPI}$

Table 8: Cost forecasting formulas

Duration forecasting

Planned value method (Anbari)	**Earned duration method** (Jacob)	**Earned schedule method** (Lipke)
$EAC(t)_{PV\,1} = PD - TV$	$EAC(t)_{ED\,1} = AD + (PD - ED)$	$EAC(t)_{ES\,1} = AD + (PD - ES)$
$EAC(t)_{PV\,2} = \frac{PD}{SPI}$	$EAC(t)_{ED\,2} = AD + \frac{(PD - ED)}{SPI}$	$EAC(t)_{ES\,2} = AD + \frac{(PD - ES)}{SPI(t)}$
$EAC(t)_{PV\,3} = \frac{PD}{CR}$	$EAC(t)_{ED\,3} = AD + \frac{(PD - ED)}{CR}$	$EAC(t)_{ES\,3} = AD + \frac{(PD - ES)}{CR}$

Table 9: Duration forecasting formulas

Specific hypothesises

The four general hypotheses can be translated into fifteen specific hypotheses that will be tested statistically and qualitatively. This huge amount of hypotheses is necessary as it is the intention of this study to investigate every aspect that might have an influence on the EVM performance in the construction industry.

The first three hypothesises consider indices stability. Stability is important because it makes accurate forecasts possible early in the project life. The CPI, SPI and SPI(t) are all tested for stability at the twenty percent completion point.

1. **H0: CPI is stable at the 20 percent completion point**
   H1: CPI is not stable at the 20 percent completion point

2. **H0: SPI is stable at the 20 percent completion point**
   H1: SPI is not stable at the 20 percent completion point

3. **H0: SPI(t) is stable at the 20 percent completion point**
   H1: SPI(t) is not stable at the 20 percent completion point

Similar stability tests are also done for the re-baselined schedules. Re-baselining is done when more information becomes available and decreases uncertainty both from a cost and duration point of view. It is expected that re-baselining has a positive influence on indices stability.

4. **H0: CPI with re-baselining is stable at the 20 percent completion point**
   H1: CPI with re-baselining is not stable at the 20 percent completion point

5. **H0: SPI with re-baselining is stable at the 20 percent completion point**
   H1: SPI with re-baselining is not stable at the 20 percent completion point

6. **H0: SPI(t) with re-baselining is stable at the 20 percent completion point**
   H1: SPI(t) with re-baselining is not stable at the 20 percent completion point

Finally a comparison can be made between indices stability for both the original and re-baselined schedule. Here the moment when stability is achieved, will be compared.

7. **H0: CPI with re-baselining achieves stability earlier in the project than without re-baselining**
   H1: CPI with re-baselining achieves stability not earlier in the project than without re-baselining

8. **H0: SPI with re-baselining achieves stability earlier in the project than without re-baselining**
   H1: SPI with re-baselining achieves stability not earlier in the project than without re-baselining

9. **H0: SPI(t) with re-baselining achieves stability earlier in the project than without re-baselining**
   H1: SPI(t) with re-baselining achieves stability not earlier in the project than without re-baselining

Hypothesis ten and eleven test the forecasting accuracy of the different forecasting methods. First the eight cost forecasting equations are compared with each other. Next a similar test is done for the nine duration forecasting equations.

10. **H0: all eight cost forecasting equations provide equally accurate cost forecasts**
    H1: there is a difference in forecasting accuracy between the eight cost forecasting equations

11. **H0: all nine forecasting equations provide equally accurate duration forecasts**
    H1: there is a difference in forecasting accuracy between the nine duration forecasting equations

In order to interpret hypothesises ten and eleven well, it is important to verify whether no other project characteristics have an influence on the behaviour of the cost and duration forecasts. If not, the hypothesises can be accepted. If however a significant influence of an external factor is detected, the results for hypothesises ten and eleven should be re-examined.

The P-factor, Serial-Parallel indicator (SP), length of the project and contract type are selected because according to the literature, these factors might have an influence. However no unified and clear opinion of their relationship exists.

12. **H0: the P-factor has no influence on duration forecasting accuracy**
    H1: the P-factor has an influence on duration forecasting accuracy

13. **H0: the SP-indicator has no influence on cost/duration forecasting accuracy**
    H1: the SP-indicator has an influence on cost/duration forecasting accuracy

14. **H0: the length of the project has no influence on CPI stability**
    H1: the length of the project has an influence on CPI stability

15. **H0: the contract type has no influence on cost/duration forecasting accuracy**
    H1: the contract type has an influence on cost/duration forecasting accuracy

Population and sample

The population is considered all large construction projects executed in Belgium the last ten years. This is a huge population. In 2005 the construction industry was responsible for 4,8 percent of the Gross Domestic Product (GDP) in Belgium and it employed around 192.000 people. (Euroconstruct)

Within the construction industry, several sub domains exist. As the focus of this study lays on large construction projects, the selected projects are all industrial or heavy/civil construction projects..

In the study data from **five construction projects** was analyzed. The data was provided by five different companies, four project organizations and one project owner. A brief overview of the projects is given in table 10. A more detailed description of every project is provided in the next section.

Project name	Project viewpoint
1. Construction of a fourteen floor building	Strabag
2. Construction of a sewage plant	Jan De Nul
3. Renovation of the construction around a railway bridge	Soetaert
4. Renovation and expansion of an eleven floor building	Louis De Waele
5. Construction of a gas compression station	Fluxys [1]

Table 10: Projects

Data collection

The data collection was a four step iterative process and is shown in figure 10. First, emails were sent out to fifty-three different companies with a description of the study, the required data and information about data integrity possibility. Only eighteen of those companies responded to our mailing, which resulted in a response rate of **34 percent**. From the eighteen responses only one was positive.

In a second phase the thirty-five companies that hadn't responded yet were telephoned. This resulted in four positive responses which set the total on five companies. Each company wanted to provide data of one project, making a total of five projects.

1Data for the Fluxys project seen from the project owner's point of view. Nevertheless the data could accurately be transformed into EVM data that represents well the project progress as noticed from the project organization's point of view. Therefore this project was included in the sample and is assumed to be representative for the study.

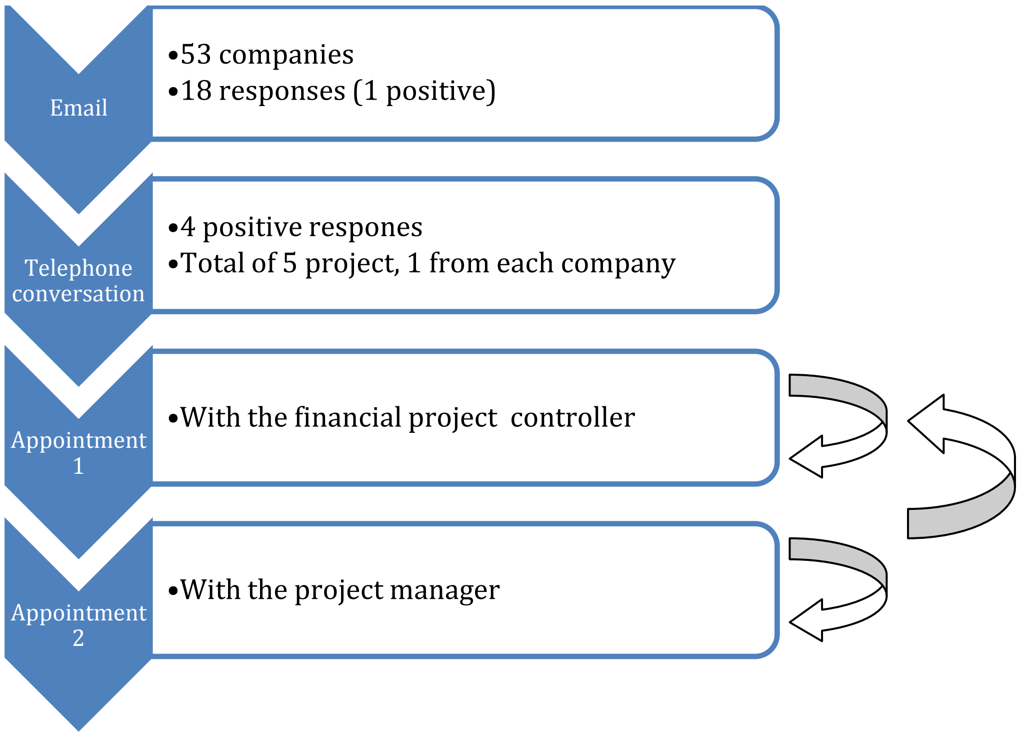


Figure 10: Data collection

The main reasons why it was so difficult to find cooperating companies can be summarized:

- Financial data needed to stay confidential
- It required too much time and effort to provide the data
- No adequate follow-up data was available (mostly companies with smaller projects)

Then the first data was received by email and an appointment was made with the financial controllers of the different projects. In this conversation it was explained which supplementary data was required to analyze the projects appropriately. A second amount of data was received by email or as hard copy in the next weeks. The project data contained the following:

- Initial plan and budget of the project
- Follow-up information about the actual cost and duration of the activities
- Adjusted plans and budgets during the project
- Final cost and duration of the project

The fourth and last step consisted of another appointment, now with the project leaders. This appointment was done while analyzing the project data. Some of the appointments were made on the site of the project itself. During this meeting more technical aspects about the projects were discussed and for many projects the distribution of the budget over the different activities on the plan were made more clear (supra data analysis). Certain project characteristics and reasons for events during the project were also explained here.

Data analysis

ProTrack, MS Excel and SPSS are the tools that were used to analyze the data. ProTrack is a project scheduling and tracking software tool based on the current best practices of EVM. It was used in a first phase of the data analysis where the different projects were analyzed separately and the necessary project metrics were calculated. In the second phase, the obtained ProTrack results were inserted in Microsoft Excel. In this spread sheet application the data was transformed into useful data for the study. Calculations were made and graphs were designed to do the qualitative analysis. Finally the data was also inserted in SPSS, an analytical software tool that was used to give statistical evidence for the proposed hypothesises.

ProTrack[2]

Pro Track is a software tool that was specifically designed for project managers to follow-up their projects. All useful EVM data can be inserted in the application and useful EVM metrics are calculated. This process will be explained first and is illustrated with an example (Appendix I).

First the project baseline is set up. In ProTrack this is done by importing the MS Project base plan and assigning a fixed and variable cost to every activity on the plan. This is the most difficult aspect in analyzing the data because generally construction companies don't assign costs to specific activities on the plan. Costs are assigned to global items like soil work, concrete work etc. To overcome this, a method is required to assign these general costs to the specific activities on the plan, while not giving a biased view of the project.

The cost assignment method consists of a two steps complementary process. On the one hand data about the budgeted cost of each month was made available by the financial project controller. On the other hand a distribution of the project cost about grouped activities on the plan was provided by the project manager. The latter requires a lot of knowledge about the construction project and therefore intervention of the project manager is absolutely necessary. With these two cost distributions, one per month and one per bunch of activities, an accurate reconstruction of the project using EVM can be established.

An example of a small project that illustrates the cost assignment method can be found in Appendix I.

Furthermore, in ProTrack a distinction is made between fixed cost and variable cost. In this study, the distribution is done in cooperation with the project manager and by using certain general rules: Wages are variable costs and materials are in most cases a fixed cost. However the rent of a tower crane is a variable cost as the rent is paid per day and not per delivery.

---

[2] Source: www.protrack.be
Accessed on 10 May 2010

When the baseline is set up, the project is tracked and followed up on a monthly basis. In ProTrack this is done by adding a period and filling in the real duration of the activities that were executed in that period. Also the actual cost deviation is inserted to calculate the Actual Cost (AC). The Earned Value (EV) is calculated automatically when the percentage completed for each activity is defined.

At the end of the project, a summarized tracking overview is available that contains all metrics and parameters that are necessary for an in-depth analysis. Table 11 shows part of a tracking overview example in ProTrack.

General	EVM key parameters			Metrics			
Name	PV	EV	AC	SPI	CPI	SPI(t)	p-factor
30/06, 2004	€ 256.631	€ 170.910	€ 177.989	67%	96%	53%	39%
31/07, 2004	€ 302.983	€ 222.234	€ 232.946	73%	95%	56%	53%
31/08, 2004	€ 374.115	€ 257.882	€ 286.098	69%	90%	51%	59%
30/09, 2004	€ 510.157	€ 320.195	€ 365.553	63%	88%	67%	63%
31/10, 2004	€ 626.311	€ 460.045	€ 542.939	73%	85%	79%	72%
30/11, 2004	€ 736.775	€ 548.512	€ 632.808	74%	87%	74%	79%
31/12, 2004	€ 749.506	€ 632.145	€ 716.841	84%	88%	75%	80%
31/01, 2005	€ 772.116	€ 709.695	€ 778.215	92%	91%	73%	81%
28/02, 2005	€ 837.219	€ 888.295	€ 978.947	106%	91%	109%	86%
31/03, 2005	€ 898.562	€ 916.104	€ 1.003.445	102%	91%	104%	88%
30/04, 2005	€ 933.743	€ 970.540	€ 1.049.643	104%	92%	107%	88%
31/05, 2005	€ 984.931	€ 1.018.762	€ 1.094.843	103%	93%	117%	87%
30/06, 2005	€ 1.004.833	€ 1.123.741	€ 1.165.801	112%	96%	123%	87%
Actual Schedule	€ 1.336.383	€ 1.336.383	€ 1.387.723	100%	96%	100%	100%

Tabel 11: Tracking overview 'ProTrack'

In the study the projects were also analyzed with the incorporation of **re-baselining**. As ProTrack doesn't incorporate re-baselining yet, a new project with a new baseline was made every time the plan changed. Based on the adjusted baseline the project was again tracked on a monthly basis and new metrics were calculated for the project.

For one project, data was obtained from the **project owner.** Because the data was presented in a different format than the other projects, an adjusted method was used to transform the data into EVM data. For the project, the construction of a gas compression station, the following data was used:

- a base cash-flow plan
- follow-up data about the actual cash-flows
- adjusted cash-flow plans
- an overview of additional work that was required

This data is very similar to the data obtained from the construction companies (supra, p.36). Because this €62 million dollar contract was followed-up very carefully, making it possible to provide accurate EVM data, the project was included in the sample.

The project baseline for this twenty-four months planned project consists of twenty-four activities, one for each month. The planned value for each activity is equal to the planned cash-flow on the base cash-flow plan. Tracking each month required extra attention. The assumption was made (and approved by the project manager) that the project owner only pays for work that was really executed. For example if the planned cash flow in the first month equals €2mio and the actual cash-flow equals only €1mio, then it is assumed that only fify percent of the work planned in the first month was completed and the EV will equal €1mio.

The actual cost deviations are incorporated as additional work required extra payments. We are aware that the actual costs in our data may not represent the actual costs from the project organization's point of view. However the project controller assured us that the applied assumption displays the reality very well.

MS EXCEL

The obtained Pro Track data was translated into useful data to execute the qualitative research and to use statistical tests. Therefore various calculations were done. For example the forecasting methods were ranked according to accuracy and an average rank was calculated per method. Also graphs were drawn to reveal possible relations. The MS Excel application served as a very complete and useful tool to support the data analysis.

SPSS

The statistical analysis was done in SPSS. As the sample only contains five projects, the hypothesises were tested with non parametric tests. Table 12 gives an overview of the tests that were used per hypothesis.

	Statistical test
Hypothesis 7	Wilcoxon signed ranks test
Hypothesis 8	Wilcoxon signed ranks test
Hypothesis 9	Wilcoxon signed ranks test
Hypothesis 10	Friedman test
Hypothesis 11	Friedman test
Hypothesis 12	Linear regression (F-test)
Hypothesis 14	Linear regression (F-test)
Hypothesis 15	Mann-whitney U test

Table 12: Used statistical tests

Hypothesises one to six could not be tested statistically because due to the sample size no distribution (normal, t, chi square, etc.) can be assumed. Therefore no confidence interval can be set up that would be used to verify stability at the twenty percent completion point.

Hypothesises seven to nine that compare stability with and without re-baselining are tested with a the Wilcoxon signed ranks test, a test for two related samples. The Friedman test, a test for multiple related samples, is used to test whether the forecasting methods perform on average equally good. If a significant difference would be detected, further post-hoc analysis is required.

For hypothesises twelve and fourteen linear regression is used to verify the relation between two project characteristics (P-factor and length of the project) and the forecasting accuracy/stability. Linear regression can be used for small samples as it does not require assumptions about the distribution of the dependent or independent variable. However it assumes that the residuals are normally distributed. This is verified with the Kolmogorov-Smirnof test.

No statistically appropriate test was available to test hypothesis thirteen.

Finally the Mann-Whitney U test is applied to test the influence of two independent samples, fixed price and cost reimbursable contracts on the forecasting accuracy/stability.

5 Projects

In this thesis five projects were analyzed to obtain information concerning the effectiveness of EVM on construction projects. To allow comparison of this effectiveness against the objectives of each project, only finished projects were considered. The entire Strabag project is still being executed but adjustments to the final objectives enabled comparison to appropriate objectives for the part of the project that has been finished.

The five projects are all situated in Belgium and were executed by private construction companies.

As can be found in table 13 the sample of construction projects ranges over budgets from one to sixty-two million EURO and for the duration this sample ranges from seven to thirty-eight months. This wide range allows us to compare the results of the EVM methods between the different projects while looking for influence of specific project characteristics.

	Jan De Nul	**Strabag**	**Fluxys**	**Louis De Waele**	**Soetaert**
Duration	18,5 months	21 months	38 months	19 months	7 months
Budget	€ 1.236.604	€2.113.000	€ 62.385.600	€15.425.816	€ 1.079.466
Network Structure	Parallel	Serial/parallel	Not available[3]	Parallel	Serial/parallel
Construction Type	Industrial	Heavy / Civil	Industrial	Heavy / Civil	Industrial
Type of Client	Public	Public	Private	Private	Public
Contract Type	Fixed Price	Fixed Price	Fixed Price	Fixed Price	Fixed Price

Table 13: Projects summary

[3] As the data from the Fluxys project was obtained from the project owner, no information about the network structure was available

HOVE 2004 – THE CONSTRUCTION OF A SEWAGE PLANT

Project Owner:

Aquafin N.V.

Dijkstraat 8, 2630 Aartselaar

Project Organization:

Jan De Nul N.V.

Tragel 60, 9308 Hofstade-Aalst

Project information:

The project consists of the construction of a small sewage plant in Hove (Antwerp). The project was finished in time and within the budget. In the beginning the project was heavily running behind schedule. After six months this delay was recovered and the project was even performing ahead of schedule. As the final date was easy to reach, fewer resources were allocated to the project and the project was finished at the planned end date.

The actual cost of the project was €90.160 less than the budget. The main reason for this was that an expected cost for pilings was not necessary anymore as the project evolved (around €60.000). Besides, efficient work progress was the other factor that decreased the actual cost.

Start date		28/04/04
End date	*Planned*	12/11/05
	Actual	12/11/05
		Delivered on time
Cost	*Planned*	€ 1.236.604
	Actual	€ 1.146.444
		-€90.160
# activities		220
Re-baselined		31/10/04
Contract type		Fixed Price

ANDERLECHT 2008 - THE CONSTRUCTION OF A 14 FLOOR KITCHEN TOWER

Project Owner:

Vlaamse gemeenschapscommissie (VGC)

Saincteletteplein 17, 1000 Brussel

Project Organization:

STRABAG Belgium N.V.

Regio West, Apostelhuizen 26, 9000 Gent

Project information:

This project considers the masonry work of a new kitchen tower for the cooking school of Anderlecht. It includes the preparation of the site, the earthwork and the raw concrete construction. The project was still running while writing the thesis so only this first part of the construction project is included in the study. The final completion for the tower is estimated on November 17, 2010.

The project started on May 5, 2008 and was originally due on August 12, 2009. Because the plans for the construction of the different floors were not provided in time by the architect, the project was soon delayed with almost four months. This delay could not be recovered because the concrete construction every time needed time to become solid before the next floor could be constructed. Besides, some small additional work was required which caused the project to be complete on January 27, 2010, five and a half month behind the original schedule.

The increase in cost of around €399.000 was mainly caused by a higher need for materials (reinforcement, driven piles, concrete) after the new plans were provided. Another part (±€100.000) was due to additional work (extra testing, elastic joints and isolation).

Start date		05/05/08
End date	*Planned*	12/08/09
	Actual	27/01/10
		+5,5 months
Cost	*Planned*	€2.113.000
	Actual	€2.512.000
		+€399.000
# activities		273
Re-baselined		31/10/08
Contract type		Fixed Price

ZELZATE 2006 – THE CONSTRUCTION OF A NEW COMPRESSOR STATION TO STORE NATURAL GAS

Project Owner:

Fluxys N.V.
Avenue des Arts 31
1040 Brussels

Project Organization:

Preferred not to be published

Project information:

The Fluxys project actually finished fourteen months behind schedule. This delay was caused by two factors. First of all procurement and engineering, two activities that depended a lot on each other, were not planned well. This resulted in a delay early in the project because materials did not arrive in time. The delay could not be recovered because when the materials arrived, the engineers were already working at full capacity and no additional resources could be made available.

Secondly, later in the project a lot of additional work was required by Fluxys. The additional work had a value of €3 million and included for example additional fire fighting protection, additional pipelines, a new security system etc. These additional activities could not be estimated on beforehand as these were discussed and approved during the project life. The additional work was charged to Fluxys, the project owner.

Start date		01/06/06
End date	*Planned*	31/05/08
	Actual	31/07/09
		+14 months
Cost	*Planned*	€ 62.385.600
	Actual	€ 65.526.925
		+€3.141.325
# activities		24
Re-baselined		31/08/07, 31/01/08, 31/08/08, 30/11/08
Contract type		Fixed price

BRUSSELS 2006 - EXPANSION OF THE FINANCE TOWER

Project Owner:

Breevast B.V.

Jan van Rijswijcklaan 162 b11, 2020 Antwerpen

Project Organization:

Interbuild N.V.

Heistraat 129, 2610 Wilrijk

Subcontractor:

Louis De Waele N.V.

Jean Dubrucqlaan 175, 1080 Brussel

Project information:

Due to the presence of asbestos and carbonation, the Finance tower had to be renovated after a lifespan of only 25 years. The project itself consisted of two parts. The first part concerned the renovation of the Finance tower while the second part consisted of building a new office building next to the tower. For this second part Interbuild N.V. formed a coalition with Louis De Waele N.V.

The project started with a three to four weeks delay but managed to finish on time. Although it was at a higher cost. The cost overrun of € 912.208 was on the one hand due to unforeseen extra resources that were necessary during the project. On the other hand additional work with a value of €423.027 was negotiated. This increase in scope was completely charged to the project owner.

Start date		15/03/06
End date	*Planned*	18/10/07
	Actual	18/10/07
		Delivered on time
Cost	*Planned*	€15.425.816
	Actual	€16.338.024
		+€ 912.208
# activities		751
Re-baselined		NO
Contract type		Fixed Price

GENT 2006 – RENOVATING THE CONSTRUCTION AROUND THE 'WIEDAUWKAAI' RAILWAY BRIDGE

Project Owner:

INFRABEL N.V.

Koningin Maria-Hendrikaplein 2, 9000 Gent

Project Organization:

SOETAERT N.V.

Esperantolaan 10A, 8400 Oostende

Project information:

The project existed of renovating the construction around the 'Wiedauwkaai' Railway Bridge, which has to protect the bridge against possible collisions.

The project was originally scheduled to start on October 9, 2006 and was due on March 19, 2007 (02/10/06 – 19/03/07). Because of the infeasibility of the original plan, Soetaert N.V. (who had won the tender) was allowed to propose an altered plan without changing the original execution term of 190 calendar days. This change of plans postponed the project start to February 1, 2007 and the end date to August 31, 2007. These changes also enabled Soetaert N.V. to alter the schedule in a way that they had more certainty about reaching the key milestones and dates.

The eventual execution of the project was finished on time and at a cost of € 1.298.291. The additional cost of €218.825 was due to extra material (poles) that was required to make the construction more solid. This cost overrun was charged to Infrabel N.V. as it was executed on their request.

Start date		01/02/07
End date	*Planned*	31/08/07
	Actual	31/08/07
		Delivered on time
Cost	*Planned*	€ 1.079.466
	Actual	€ 1.298.291
		+€218.825
# activities		48
Re-baselined		NO
Contract type		Fixed Price

6 Results

The results of this study will be presented as follows: First the results of the indices stability (CPI, SPI and SPI(t)) are discussed. Secondly the different cost and duration forecasting methods are compared with each other for their predictive power. Thirdly a comparison is made between EVM on the original schedule and on the re-baselined schedule. Finally the influence of the different project characteristics (p-factor, serial-parallel factor, length of the project, contract type) on the use of EVM in the construction sector is presented.

Indices stability

Stability of the indices is very important because the indices measure performance and are used in the different cost and duration forecasting equations. When the indices are stable early in the project, good forecasting estimates can be made early in the project and the risk of project failure decreases.

Figure 11 presents the results of CPI, SPI and SPI(t) stability. It shows on the Y-axis the cumulative number of projects that obtain stability at time t (expressed as percentage completed on the X-axis). This is presented similar to other studies such as: Payne (1990), Christensen and Heise (1993), Lipke (2004) which also assume stability when the deviation between the index at completion and the index at time t is less than ten percent. For a more detailed overview of stability per project can be referred to Appendix II.

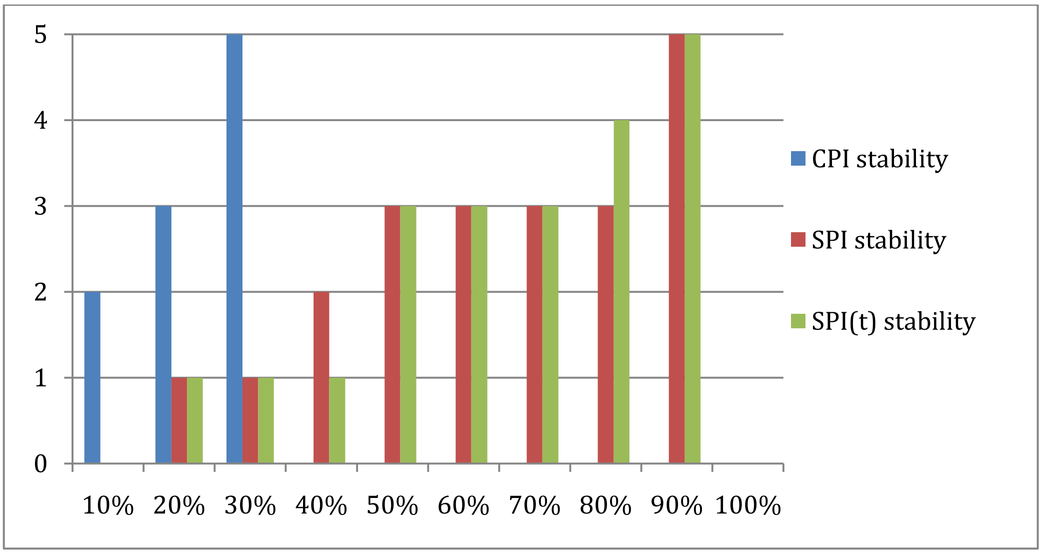


Figure 11: Cumulative stability of indices

Three out of five projects achieve cumulative CPI stability before the twenty percent completion point. In the literature this is the generally accepted milestone at which stability should be achieved (Christensen 1993; Fleming and Koppelman, 1996). As the other two projects are stable before the project is thirty percent completed, CPI stability cannot be ignored in this study.

SPI and SPI(t) stability on the other hand cannot be noticed early in the project. Only one project achieves stability before the twenty percent completion point. At the fifty percent completion point only three projects achieved stability. For the remaining projects stability is only achieved late in the project. The hypothesis of SPI and SPI(t) stability at the twenty percent completion point can therefore be intuitively rejected, as no appropriate statistical tests are available.

Certain reasons can be found why the CPI is more stable than the SPI and SPI(t) in the construction sector. First of all the SPI performs very bad for projects that finish far behind schedule. As Lipke already noted, the SPI always returns to one at the end of the project and therefore does not represent a realistic view of the delay. Figure 12 shows an example of a project from our sample that finished behind schedule. It can be noticed that the SPI returns to one at the end of the project. Due to this necessary increase, SPI stability is achieved much later than SPI(t) stability for this project.

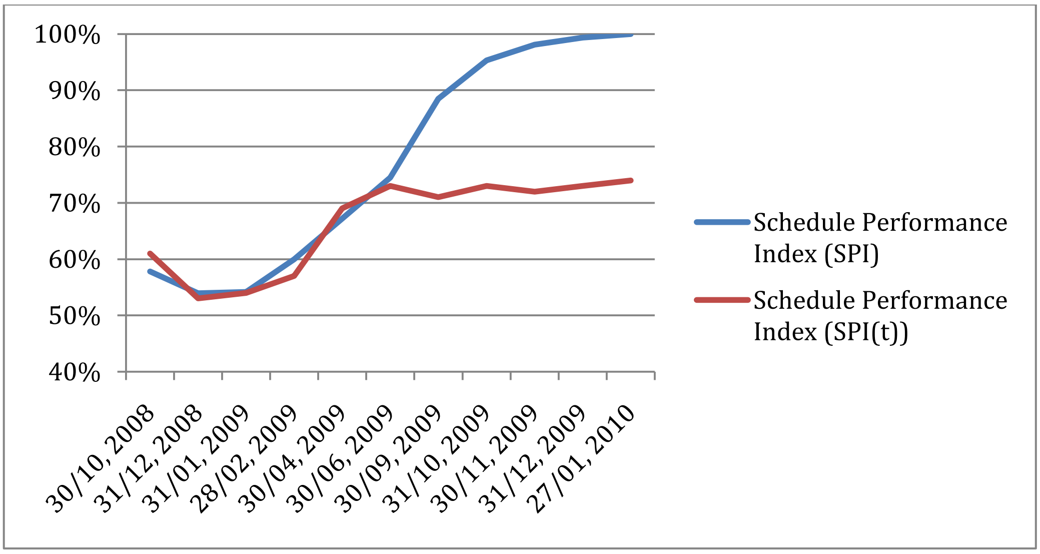


Figure 12: SPI versus SPI(t)

The results from this study however also revealed that next to SPI stability, also SPI(t) stability is not achieved early in the project. As SPI(t) overcomes the problem of returning back to one at the end of the project, other causes for instability should be present. Taking a deeper look on the construction projects, two irregularities emerge. First of all, a **slow start-up phase** was no coincidence as a significant delay in the first twenty percent of the project was noticed for four of the five projects. Table 14 gives an overview of these findings. Reasons for the slow start-up varied from architectural plans that were not ready and bad procurement planning to the temporarily allocation of workforce to other, more important projects that needed to reach the final deadline. The slow start-up for most projects was recovered during the project but inhibited stability early in the project.

	SPI(t) at 20 percent completion
Fluxys	57%
Jan De Nul	60%
Strabag	58%
Soetaert	60%
Louis De Waele	108%

Table 14: SPI(t) at 20 percent completion

Secondly, during project execution and especially at the end of the project, the plans were often changed which triggered additional work and replaced some activities by others. The presence of **changes to the plan** is a typical characteristic of the construction sector. Even though all five projects are fixed price contract projects – the contract type that generally sticks best to the original plan – all five projects were confronted with changes in the base plan. These changes often have a higher influence on the schedule performance than on the cost performance of a project. Adjustments to the project mostly require the preparation of new plans, other materials that have to be procured and often the workforce is not as skilled for the new job as for the originally planned job. All these factors cause the project to perform poorer than planned. This while the cost of these activities often does not change a lot in comparison with the cost of the originally planned work. This may explain why SPI and SPI(t) stability are achieved later compared to CPI stability, in the construction industry.

Forecasting methods

The different forecasting methods for cost and duration were tested on their predictive power in forecasting the final cost and duration. First a comparison of the performance of the eight cost forecasting methods is presented. Next a similar overview is given for the nine duration forecasting methods.

Cost forecasting methods

The eight cost forecasting equations differ from each other by the performance factor that is used to discount the planned remaining cost. To study the difference in forecasting accuracy between them, a ranking from 1 to 8 is assigned for each project (1 for the best forecasting method and 8 for the worst forecasting method). The results are summarized in table 15.

	EAC_1	EAC_2	EAC_3	EAC_4	EAC_5	EAC_6	EAC_7	EAC_8
Fluxys	4	3	5	7	6	8	1	2
Jan De Nul	4	1	8	7	6	5	2	3
Strabag	4	3	6	5	7	8	2	1
Soetaert	6	7	2	8	1	5	4	3
Louis De Waele	2	1	7	5	8	6	4	3
Total	**20**	**15**	**28**	**32**	**28**	**32**	**13**	**12**
Average rank	**4**	**3**	**5,6**	**6,4**	**5,6**	**6,4**	**2,6**	**2,4**

Table 15: Ranking of the cost forecasting methods

EAC_8 and EAC_7 perform on average best for this sample of five projects. Also EAC_2 provides reliable cost estimates, with exception for the Soetaert project. The equations are given below:

$$EAC_8 = AC + \frac{BAC - EV}{0{,}8 * CPI + 0{,}2 * SPI(t)}$$

$$EAC_7 = AC + \frac{BAC - EV}{0{,}8 * CPI + 0{,}2 * SPI}$$

$$EAC_2 = AC + \frac{BAC - EV}{CPI}$$

It should be noted that all three equations have a performance factor that depends heavily on the CPI. EAC_8 and EAC_7 add a fraction of the SPI(t), respectively SPI to the performance factor. However the CPI is with a fraction of 0,8 still the dominant component. EAC_2, the generally most accepted cost forecasting equation by project managers, also performs well, which is in line with the literature. Nevertheless it performs worse than the two best performing equations. EAC_3, EAC_4, EAC_5 and EAC_6 with performance factors equal to SPI, SPI(t), CR and CR(t) perform worst due to the less stable schedule performance indicators which have a larger impact on these equations.

Statistical tests also confirm that there is a significant difference between the performance of the eight cost forecasting methods. Moreover a post-hoc analysis with the Wilcoxon signed ranks test shows that EAC_2, EAC_7 and EAC_8 perform significantly better than EAC_4 and EAC_6. For these results can be referred to Appendix III, 2.

From these results can be noticed that the incorporation of a small fraction of a schedule performance indicator can be beneficial for the forecast but only to some extent. The performance factor should be mainly influenced by the CPI for cost forecasting. Therefore the general acceptance of EAC_2 formula to forecast the final cost is confirmed by the present results.

Duration forecasting methods

Generally three main duration forecasting methods exist: the Planned Value, Earned Duration and Earned Schedule method. All three methods were tested with a performance factor equal to one, the SPI and the CR (respectively SPI(t) and CR(t) for the ES method) resulting in nine forecasting equations. Again the equations were ranked from one to nine with one for the most accurate forecasting equation. The results are summarized in table 16.

	Planned Value method			**Earned Duration method**			**Earned Schedule method**		
	$EAC(t)_{PV1}$	$EAC(t)_{PV2}$	$EAC(t)_{PV3}$	$EAC(t)_{ED1}$	$EAC(t)_{ED2}$	$EAC(t)_{ED3}$	$EAC(t)_{ES1}$	$EAC(t)_{ES2}$	$EAC(t)_{ES3}$
Fluxys	9	6	5	8	4	3	7	2	1
JDN	3	7	6	1	7	4	2	9	5
Strabag	5	9	8	2	4	7	1	3	6
Soetaert	1	4	9	2	4	7	3	6	8
LDW	2	7	9	3	6	8	1	4	5
Total	**20**	**33**	**37**	**16**	**25**	**29**	**14**	**24**	**25**
Avg rank	**4**	**6,6**	**7,4**	**3,2**	**5**	**5,8**	**2,8**	**4,8**	**5**

Tabel 16: Ranking of duration forecasting methods

The results show that $EAC(t)_{PV1}$, $EAC(t)_{ED1}$ and $EAC(t)_{ES1}$ provide on average the most accurate duration forecasts. These are three different methods with a common performance factor equal to one. As the difference in average rank with the other performance factors is large, it can be supposed that a performance factor equal to one is necessary to make accurate duration forecasts. While a performance factor equal to the SPI or CR implies a continuous trend in performance during the project, a performance factor of one implies that the remaining activities are executed according to the original plan, no matter what the previous performance looked like.

A good reason for this can be found by taking a closer look at the characteristics of construction projects. A construction project is mostly a chain of separated activities (for example foundation work, masonry work, joinery, painting etc) where the next activity can only start when the previous activity has finished (serial network structure). Therefore, it is hard to catch up delays. Besides most of the activities in construction projects are activities that are similar, to some extent, to other construction projects. This implies that project leaders with a lot of experience can make rather good cost and duration estimates for almost all activities at project initiation. So when the project falls behind for a certain reason, no extrapolation of that performance should be done. The estimate for the remaining duration of the project can often still remain unmodified.

Another observation that is done when looking at table 16 is that the Earned Schedule method provides the best duration forecasts of the three forecasting methods. The Earned Duration method gives the second best results and the Planned Value method performs worst. Although the sample size is small, these results confirm the general existing idea of superior ES performance (Lipke, 2009; Vanhoucke, 2007).

No significant difference is found between the rankings of the nine forecasting equations when assuming the complete sample (see Appendix II, table 32). If however the Fluxys project - a project that acted completely different than the other projects due to a lot of additional work at the end of the project - is excluded from the sample, a significant difference is found between the nine forecasting equations (see Appendix III, table 33). The Wilcoxon signed ranks test then even reveals a significant better performance of EAC_{PV1} compared to EAC_{PV2} and EAC_{PV3}, EAC_{ED1} compared to EAC_{ED2} and EAC_{ED3} and EAC_{ES1} compared to EAC_{ES2} and EAC_{ES3}. No significant better performance was found for the ES method in comparison with the PV and ED method. For an overview of the statistical results can be referred to Appendix III, 3.

Re-baselining

During the lifetime of a project it might be appropriate to change the baseline when the current baseline does not give a good representation of reality anymore. This way new information about the project can be incorporated which allows the new baseline to account for changes like additional work and modifications of activities. Besides, working with a new baseline allows the different indices (CPI, SPI and SPI(t)) to return to one. In general this will allow stability of the indices to be reached earlier in the project and allows for more accurate cost and duration forecasts to be made. However re-baselining has its cost. Re-baselining requires a lot of effort as new plans have to be designed and new cost estimates have to be made. So the question can be asked whether and when re-baselining is worth the effort. Both its influence on the stability of the indices and on the forecasting methods is studied. To conclude this part, one of the projects where re-baselining turned out to be disadvantageous will be discussed.

Indices stability

First the stability of the indices is compared between the original project baseline and the re-baselined schedule. Only three projects are included in the sample as only for these projects data was available to effect a re-baselined schedule. Figure 13 gives an overview of the average moment in the project (expressed as percentage completed) when stability was obtained.

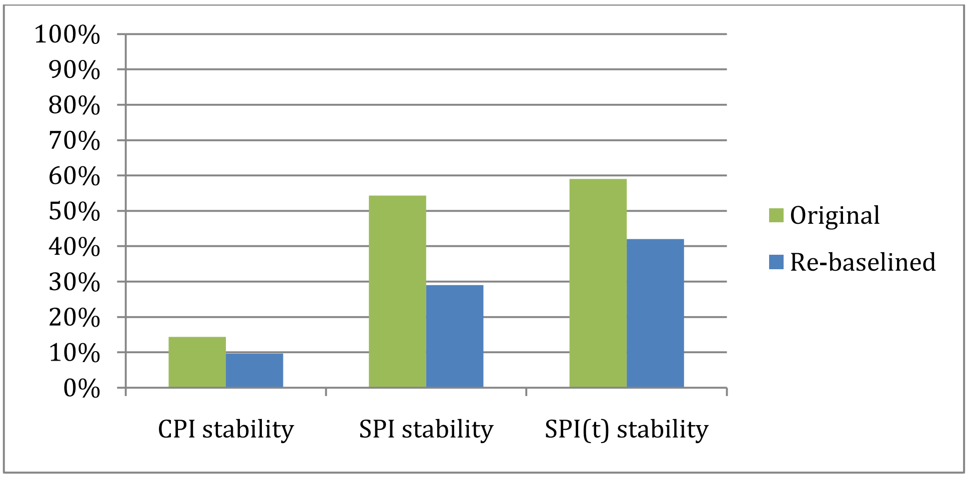


Figure 13: Stability of original vs. re-baselined

For all indicators stability is achieved earlier in the project when re-baselining is done. Based on the original baseline, CPI stability was on average obtained at the 14 percent completion point. After re-baselining this was obtained at the 10 percent completion point. SPI stability improved from the 54 to the 29 percent completion point, a decrease of 25 percent. SPI(t) stability finally ameliorated from the 59 percent to the 42 percent completion point. This improvement in indices stability is a first indicator that re-baselining could be favourable.

The Wilcoxon rank sign test however does not show a significant influence of re-baselining on indices stability. These results can be found in Appendix III, 1.

Forecasting methods

Because the indices are used in the forecasting equations, more stable indices should result in more accurate forecasts. Therefore a comparison is made between the forecasting accuracy of the re-baselined schedules and the original schedules, for both the cost and duration forecasts. First the average spread of the different forecasting methods is compared per project. This will give a general overview of the forecasting accuracy with and without re-baselining. Secondly the different forecasting methods are ranked again and compared with each other to investigate the influence of re-baselining on the individual forecasting methods.

Spread between the forecasting methods

For each project and for all eight cost forecasting methods, the average forecasting error was calculated. Per project the methods with the lowest and highest average cost deviation were selected and called the minimum, respectively maximum. Table 17 presents an overview of these results for each project. The spread is calculated by subtracting the minimum from the maximum. For example for the original Strabag schedule the best and worst forecasting methods had an average forecasting error of € 55.277 and € 445.864. When however re-baselining was done on the project, the best and worst forecasting methods had an average forecasting error of € 6.282 and € 39.786. This resulted in a decrease in spread from € 390.587 to € 33.504, equal to 91,4 percent.

	MIN	MAX	SPREAD	DEVIATION
Fluxys	€ 1.051.170	€ 12.721.468	€ 11.670.297	
Fluxys RB	€ 1.649.755	€ 2.958.316	€ 1.308.561	-88,8%
Jan De Nul	€ 13.360	€ 213.065	€ 199.705	
Jan De Nul RB	€ 9.081	€ 11.788	€ 2.706	-98,6%
Strabag	€ 55.277	€ 445.864	€ 390.587	
Strabag RB	€ 6.282	€ 39.786	€ 33.504	-91,4%

Table 17: Cost forecasting error of original vs. re-baselined

From the table can be seen that the spread between the different cost forecasting equations decreased enormously when re-baselining was done. With an average decrease of almost 93 percent it can be concluded that re-baselining has a very positive effect on the spread between the worst and the best cost forecasting methods.

A similar table was obtained for the duration forecasts, now expressed in days (see table 18). Here an average decrease in spread of 83 percent was noticed. This confirms the previous results and it can be concluded that re-baselining has a positive effect on the spread of both the cost and duration forecasting methods.

	MIN	MAX	SPREAD	DEVIATION
Fluxys	210 days	391 days	181 days	
Fluxys RB	266 days	322 days	56 days	-69,1%
Jan De Nul	21 days	120 days	99 days	
Jan De Nul RB	7 days	9 days	2 days	-98,0%
Strabag	36 days	144 days	108 days	
Strabag RB	31 days	49 days	18 days	-83,3%

Table 18: Duration forecasting error of original vs. re-baselined

The importance of this finding is the fact that through re-baselining even the forecasting error of the worst forecasting methods is a lot more acceptable. So for projects where it is hard to figure out which forecasting method to use due to uncertainty, re-baselining could be very useful as it reduces the average forecasting error. Therefore it can be supposed that the higher the uncertainty and the higher the risk of the project, the more re-baselining becomes valuable.

Comparison of the forecasting methods

Another factor that is investigated is the impact that re-baselining has on the accuracy of the different cost forecasting methods. Table 19 presents an overview of the ranking of the different forecasting methods. A ranking equal to one again stands for the best cost forecasting method and a ranking of eight for the worst.

	EAC_1	EAC_2	EAC_3	EAC_4	EAC_5	EAC_6	EAC_7	EAC_8
Fluxys	4	3	5	7	6	8	1	2
Jan De Nul	4	1	8	7	6	5	2	3
Strabag	4	3	6	5	7	8	2	1
Total	**12**	**7**	**19**	**19**	**19**	**21**	**5**	**6**
Average rank	**4,0**	**2,3**	**6,3**	**6,3**	**6,3**	**7,0**	**1,7**	**2,0**
Fluxys RB	5	6	8	1	7	2	3	4
Jan De Nul RB	1	6	3	2	7	8	5	4
Strabag RB	4	2	7	5	8	6	3	1
Total	**10**	**14**	**18**	**8**	**22**	**16**	**11**	**9**
Average rank	**3,3**	**4,7**	**6,0**	**2,7**	**7,3**	**5,3**	**3,7**	**3,0**

Table 19: Cost forecasting ranking original vs. re-baselined

Where for the original schedules the top three was occupied by EAC_7, EAC_8 and EAC_2, for the re-baselined schedules EAC_4, EAC_8 and EAC_1 perform best. The latter have a performance factor equal to the SPI(t), 0,8*CPI + 0,2*SPI(t) and 1. The finding that a performance factor equal to one performs better after re-baselining can be easily explained. Re-baselining is often done when there is more certainty about the future activities in the project. This implies that more accurate cost forecasts about the future can be made and therefore a performance factor equal to one will be more accurate. A clear reason why the SPI(t) suddenly turns out to be the best performance factor is not found. What can be explained, is that the SPI(t) is a better performance factor than the SPI by the already explained fact that the SPI returns back to one and is therefore an unreliable index at the end of the project.

The ranking of the different duration forecasting methods is presented in table 20**.** Two remarks can be made here. First, while without re-baselining the Earned Schedule method gave the best estimates, the method performs worst when re-baselining is done. Besides the Earned Duration method now outperforms the other two methods. An explanation for these results is that the ES method is too sensitive for the many changes to the plan at the end of the project, as it is expressed in time values. At the end of the project, all three projects could not stick to the re-baselined schedule. The Fluxys and Strabag project were confronted with delays due to additional work. The Jan De Nul project on the other hand was running ahead of schedule but decided to allocate less resources to the project at the end, to make the project finish just on time. This resulted in very unrealistic and unstable SPI(t)'s for the projects during this last phase of the project. The SPI's on the other hand gave better estimates as they are expressed in monetary terms which were more stable after re-baselining. Therefore the SPI was a better indicator than the SPI(t) for the three projects. As the ED and PV methods incorporate the SPI, these forecasts turned out best while the ES method that uses the SPI(t) to forecast duration performs worst for our sample. These results confirm Vanhoucke and Vandevoorde (2008) who concluded that when the schedule performance indicators do not give a reliable estimate of the project progress during the project lifecycle, which was the case for all three projects after re-baselining, ES performs worse than PV and ED.

	Planned Value method			**Earned Duration method**			**Earned Schedule method**		
	$EAC(t)_{PV1}$	$EAC(t)_{PV2}$	$EAC(t)_{PV3}$	$EAC(t)_{ED1}$	$EAC(t)_{ED2}$	$EAC(t)_{ED3}$	$EAC(t)_{ES1}$	$EAC(t)_{ES2}$	$EAC(t)_{ES3}$
Fluxys	9	6	5	8	4	3	7	2	1
JDN	3	7	6	1	7	4	2	9	5
Strabag	5	9	8	2	4	7	1	3	6
Total	17	22	19	11	15	14	10	14	12
Average rank	5,7	7,3	6,3	3,7	5,0	4,7	3,3	4,7	4,0
Fluxys	9	3	5	4	1	2	8	6	7
JDN	2	3	9	1	3	5	6	8	7
Strabag	2	5	9	1	4	6	3	7	8
Total	13	11	23	6	8	13	17	21	22
Average rank	4,3	3,7	7,7	2,0	2,7	4,3	5,7	7,0	7,3

Table 20: Duration forecasting original vs. re-baselined

A second finding from table 20 is that a performance factor equal to one can still be seen as the best performance factor to estimate the final duration. A similar explanation as in cost forecasting can be given. Because after re-baselining more certainty about the future of the project is incorporated in the project baseline, the remaining activities will be more inclined to follow this new schedule. It is also clear from the table that a performance factor equal to the CR (respectively CR(t)) results in the worst estimates.

Re-baselining might also be disadvantageous

During the analysis of the Fluxys project the remarkable finding was done that re-baselining might not be a good option for all projects. The Fluxys project was a project that was originally planned to have a duration of twenty-four months but turned out to have an actual duration of thirty-eight months due to delays and additional work that was required. The actual cost of the project was € 65.526.928, more than three million more than what was originally planned. During the lifespan of the project four re-baselines have been executed. The last re-baseline, nine months before the actual finish, estimated that the project would cost € 64.565.684 and would finish within two months, a huge mistake.

For this re-baselined project it turned out that SPI(t) stability was found later in the project. Besides the best duration forecasting methods gave better forecasts with the original schedules than with re-baselined schedules. Table 21 gives an overview of when stability is obtained for the Fluxys project.

CPI stability		**SPI stability**		**SPI(t) stability**	
Original	*Re-baselined*	*Original*	*Re-baselined*	*Original*	*Re-baselined*
3%	3%	44%	38%	79%	84%

Tabel 21: Indices stability of the Fluxys project, original vs. re-baselined

The fact that re-baselined SPI(t) stability is worse than the original SPI(t) stability is very unusual but can be explained by taking into account the huge unexpected delay that was even not taken into account when a last re-baseline was done. When looking at table 22, at the moment when the last re-baseline was executed for the project (30/11/08) the SPI(t) of the re-baselined version was set back to 100 percent. Without re-baselining the SPI(t) remained 76 percent.

	SPI(t) without RB	**SPI(t) with RB**
SPI(t) at 30/11/08	76%	100%
-20% due to unforeseen work	14%	20%
SPI(t) at the end	62%	80%

Tabel 22: SPI(t) of the Fluxys project, a comparison

Normally the re-baselined version has better forecast estimates about future duration but for this project this was not the case. Due to the unforeseen additional work the SPI(t) declined with twenty percent for both the original and re-baselined situation. So at the end of the project the final SPI(t) was 62, respectively 80 percent resulting in a 14 and 20 percent decrease in comparison with the values at November 30th.

As stability in the study is achieved within a 10 percent deviation it can be explained that the 14 percent deviation of the original schedule reaches the 10 percent stability boundary earlier than the re-baselined 20 percent deviation.

The better forecasting accuracy of certain duration forecasting methods is more difficult to explain. Figure 14 gives an overview of the average forecasting error of the different method, for both the original and re-baselined schedule. From the figure can be seen that for $EAC(t)_{ES2}$, $EAC(t)_{ES3}$, $EAC(t)_{ED2}$ and $EAC(t)_{ED3}$ the estimates were more reliable without re-baselining than when re-baselining was executed.

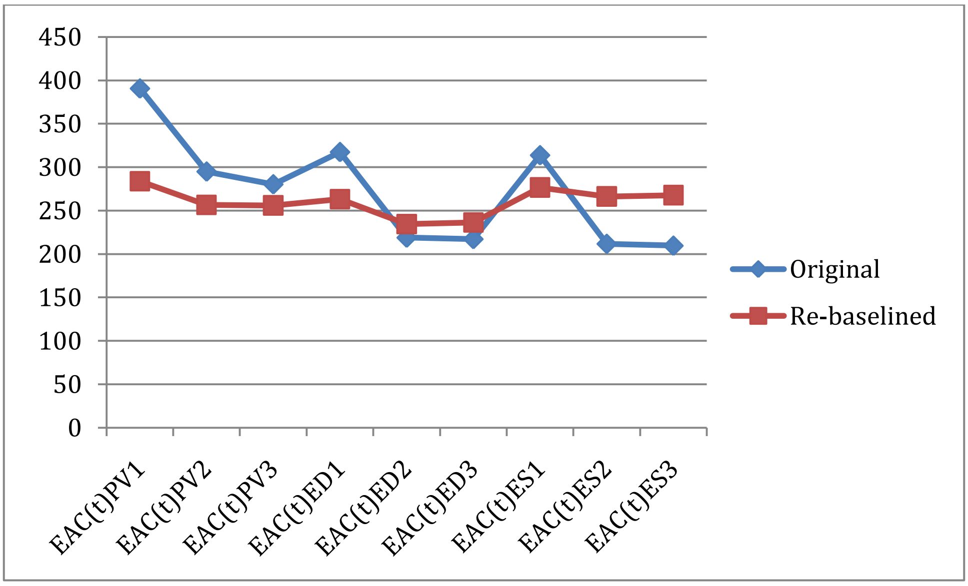


Figure 14: Duration forecast methods of the Fluxys project, original vs. re-baselined[4]

An answer for this behaviour can be found by looking at the influence that re-baselining had on the behaviour of the SPI and SPI(t) of this project. During the project, four re-baselined schedules were made, on average one every six months. Every time after re-baselining was done, the first months followed the schedule rather well, resulting in a SPI and SPI(t) close to one and very underestimating estimates for the final duration. After some months the schedule started falling behind, resulting in a lower SPI and SPI(t) and more accurate duration forecasts. This however did not last for a long time as the next re-baseline was executed soon. When re-baselining was not executed and the original baseline was kept, this leaded to a more continuously low SPI and SPI(t) and therefore more accurate estimates for $EAC(t)_{ES2}$, $EAC(t)_{ES3}$, $EAC(t)_{ED2}$ and $EAC(t)_{ED3}$.

From figure 14 can also be noticed that while originally ES outperformed PD and ED, after re-baselining ES performed worst. This can again be explained because the schedule performance

[4] Figure 14 also shows the decrease in spread after re-baselining (supra, p54)

indicators after re-baselining did not give a reliable estimate of the project progress during the project lifecycle. According to Vanhoucke and Vandevoorde (2008) these are no 'normal' conditions (supra, p.18) and under these conditions ES performs worse than PD and ED

Summarized it turned out that not for all projects re-baselining resulted in better estimates about the duration of a project. If huge unforeseen deviations are not incorporated in the re-baselined schedule, the indices can be less stable than the original schedule which can result in worse forecasts. However it should be said that this was a very exceptional project and it should not endanger the general finding that re-baselining proved to be very beneficial. It should rather make the project manager aware of the fact that re-baselining should only be executed when a significant increase in certainty about the project becomes available. If not, re-baselining should at least be executed with a lot of care and with a good understanding of its impact on the forecasts.

Project characteristics

In the literature it is believed that certain project characteristics might have an influence on the use of EVM. Nevertheless studies have never been able to give a clear answer resulting two camps of believers and non-believers. In this study it was the goal to get an insight on the influence of four characteristics that were discussed in this paper: p-factor, Serial-Parallel indicator, length of the project and contract type. An overview of the results is presented in this order.

P-factor

The p-factor is an index that measures schedule adherence. Lipke (2004) noticed the importance of the p-factor as it verifies whether the different activities are executed in the same order as planned. Not sticking to this order might increase the risk of possible rework when activities are already started before its predecessors are completely finished. Figure 15 gives an overview of the evolution of the p-factor for the different projects. The X-axis represents the percentage completed of the project. It should be noted that the Fluxys project is kept out of the sample because for this project the data was received from the project owner so no reliable p-factor could be calculated.

The p-factor of the four projects is generally high. All projects have a p-factor of more than 80 percent after thirty percent completion. Therefore conclusions are difficult to make. The Strabag project has the best p-factor. It does not fall under 95 percent during the entire project. While the Soetaert project has a continuously increasing p-factor, a more fluctuating pattern is noticed for the Jan De Nul and Louis De Waele project. It can be seen that the Louis De Waele project has the lowest p-factor of all four projects.

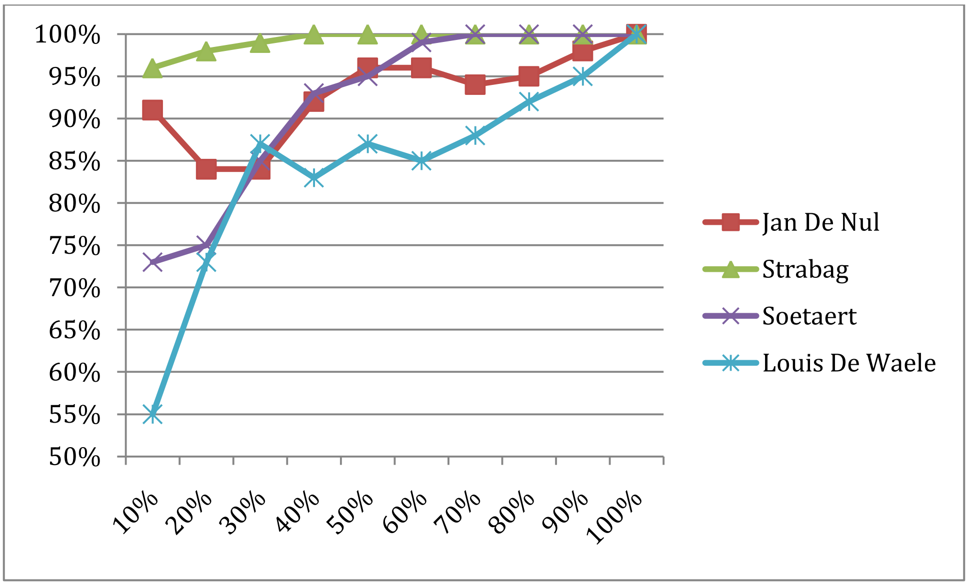


Figure 15: P-factor of the projects

The average p-factor can be compared with the average forecasting error of the four projects. This way the relation between the p-factor and forecasting accuracy can be tested. According to the literature it should be expected that the higher the average p-factor, the lower the average forecasting errors. Table 23 gives per project an overview of the results.

	Jan De Nul	**Strabag**	**Louis De Waele**	**Soetaert**
Average cost forecasting error	8,67%	8,78%	6,07%	10,02%
Average duration forecasting error	14,33%	15,08%	9,37%	10,62%
Sum of forecasting errors	**23%**	**23,86%**	**15,44%**	**20,64%**
Average p-factor	**93%**	**99%**	**85%**	**92%**

Table 23: Average forecasting error vs. P-factor

From the table can be seen that the Louis De Waele project is having better forecasting estimates than the other projects, for both cost and duration forecasting. This project also has the lowest average p-factor assuming an unexpected reverse relationship between the average p-factor and the forecasting error. Also the other projects confirm this relationship. It turns also out for them that the higher the average p-factor, the higher the sum of the forecasting errors.

No statistical evidence was found. Linear regression was done but because the residuals did not follow the normal distributions, no conclusions could be drawn. The results are presented in Appendix III, 4.

No supporting explanation for this finding can be found in literature. Neither can it be explained by taking a look at the other project characteristics. As all p-factors were very high it should be made clear that generalizations of this finding cannot be made based on this study. Therefore further research with a larger sample size is definitely required.

Serial-Parallel factor (SP)

The serial-parallel factor measures how close the schedule approaches a complete parallel network structure (SP equal to zero) or a complete serial network structure (SP equal to one). Vanhoucke and Vandevoorde (2009) concluded that the closer the network follows a serial structure, the better the forecast estimates should be for all duration forecasting methods. This is tested in this study on a sample of four projects. Again the Fluxys project is excluded from the sample as no realistic estimation for the SP could be made.

Table 24 presents the Serial-Parallel factors for the different projects. The Louis De waele project (renovation and expansion of an eleven-floor building) approaches a 100 percent parallel configuration very well. This is due to the fact that the different activities could be executed simultaneously, but on different floors. So for example while on the first floor they were busy painting, at the second floor the electricity could be arranged and at the third floor plumbing could be done.

	Jan De Nul	Strabag	Soetaert	Louis De Waele
Serial-parallel indicator	0,12	0,47	0,48	0,02

Table 24: Serial-Parallel indicator

As also the Jan De Nul project approaches more a parallel distribution and the other two projects are located between the two extremes, the general image of construction projects being more serial does not count for these projects.

Figure 16 shows the average forecasting deviation for the nine forecasting methods, for each project. According to Vanhoucke and Vandevoorde (2009) the Strabag and Soetaert project should have a lower forecasting deviation than the other two projects and therefore their lines should be located lower on the graph than the other two lines.

These results (see figure 16) do not provide a clear view related to the conclusion found in literature. The Soetaert project generally produces good forecasts while having the highest SP-indicator and the Jan De Nul project produces rather bad forecasts while having a low SP-indicator, which is in line with the literature. On the other hand, the Louis De Waele project also performs well while having the lowest SP and the Strabag project that has a high SP produces rather bad forecasts in comparison with the other projects.

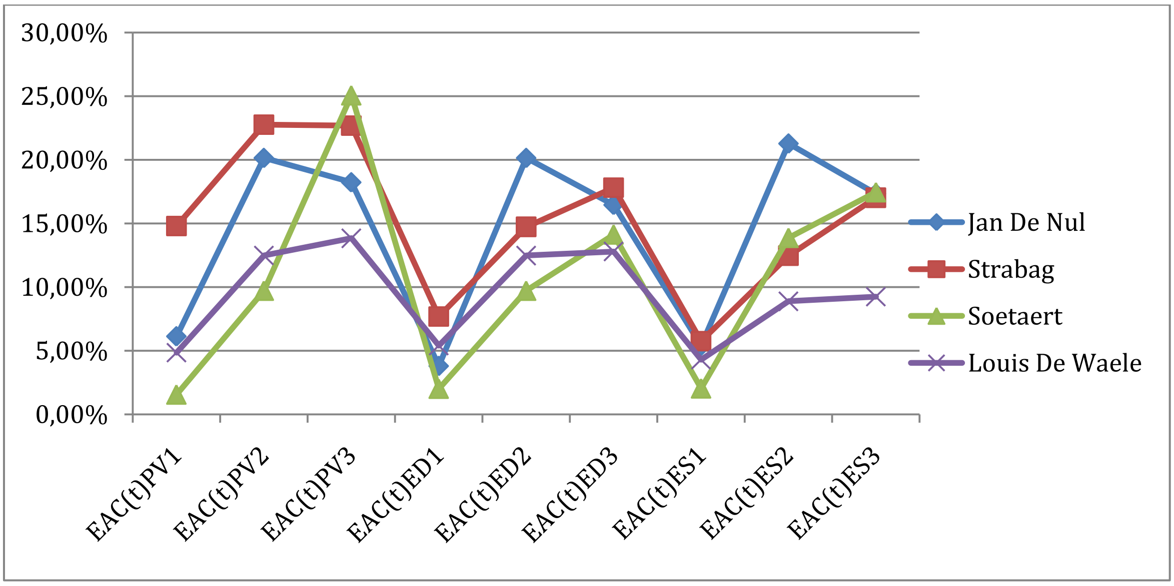


Figure 16: Average forecasting deviation per forecasting method

As the Soetaert and Jan De Nul project support Van Houcke and Vandevoorde's results, the Louis De Waele and Strabag project support the opposite relation. Therefore this study does not provide a clear answer to the question which influence the SP-indicator might have.

Length of the project

The length of the project is also supposed to have an influence on EVM. According to Fleming and Koppelman (1996) and Lipke (2006), projects with a longer duration have more chance to be CPI stable before the twenty percent completion point. The graph on figure 17 shows on the one hand the moment when CPI stability is reached (as percentage completed) and on the other hand the length of the project (in months).

From the graph can be concluded that there is an inverse relation between the length of the project and the moment when CPI stability is obtained. For the thirty-eight month lasting Fluxys project CPI stability was found when the project was only three percent completed. The shortest seven month lasting Soetaert project on the other hand obtained CPI stability last, when the project was twenty-nine percent completed.

Similar to the influence of the p-factor also here no statistical conclusions can be made. Although linear regression was executed, again the residuals were not normally distributed. As this is assumed by linear regression, no statistical evidence can be presented (see Appendix III, 5).

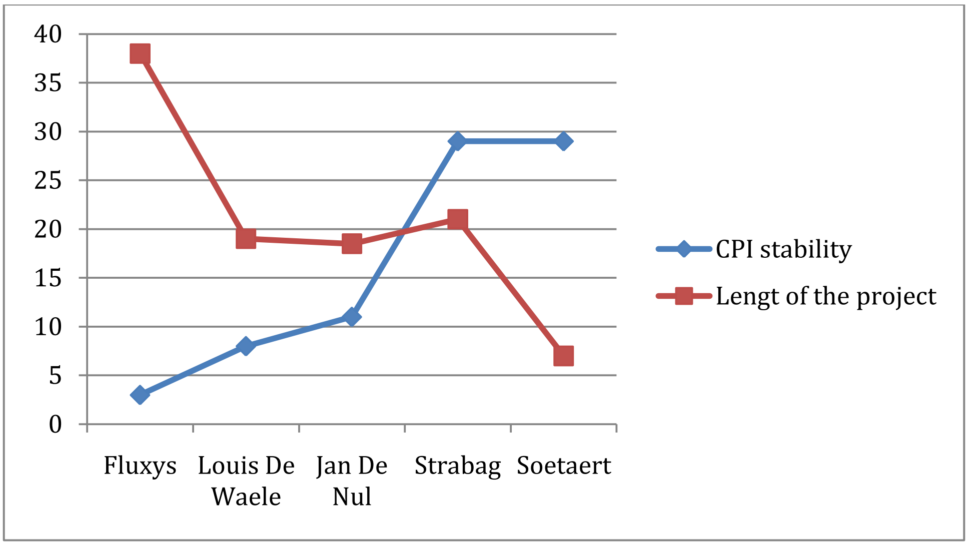


Figure 17: CPI stability vs. Length of the project

Nevertheless from the qualitative study it can be concluded that the results support the already existing believe that the length of a project has a positive influence on CPI stability.

Besides the CPI, also the relation between the SPI, respectively SPI(t) and the length of the project was studied but no relation was found for these indices. The details can be found in Appendix III, 6.

Contract type

The type of contract is the fourth and last factor that is believed to have an influence on the performance of EVM. In this study it was the intention to test projects with different contract types and compare the performance. Unfortunately the five projects that are included are all fixed price (also called lump sum) contracts. Therefore no comparison can be made to test the influence of the contract type.

7 Conclusions

The present thesis which studied a sample of five Belgian construction projects, provided valuable information on different aspects related to the EVM methodology. Although the sample size may be small, it is believed that these five projects give a rather reliable overview of construction projects in Belgium. First, the results with respect to indices stability and forecasting accuracy obtained from testing will be highlighted. Secondly, time was spent on the potential influence re-baselining and project characteristics may exert on EVM effectiveness. At last, the EVM implementation in the construction industry and the associated requirements are studied.

Indices stability

CPI stability in this sample was achieved in three out of five projects before the twenty percent completion point and all five projects achieved CPI stability before the thirty percent completion point. This is in line with the suggestions in the literature and is important for the forecasting methods using this indicator.

No stability could be found early in the project life after analyzing the stability for the other indicators (SPI and SPI(t)). A remarkable result in the present study was the different trajectories both indicators follow. As SPI always equals one at the end of the project, it explains that for projects which run far behind (or ahead of) schedule, the ten percent stability boundaries are reached late in the project life. SPI(t) does not encounter this problem of convergence which enables it to achieve stability earlier if consistent schedule performance is present. However, a consequence for the more realistic representation is that SPI(t) is also much more subject to changes and therefore will not achieve stability earlier if the performance level is not consistent.

Forecast accuracy

This study suggests that when EVM methodology is used at project initiation, **cost forecasting** methods where the performance factor is mostly determined by the CPI, will provide best estimates for the actual cost at completion. These methods perform well since the CPI gives a good representation for future cost performance and stability is achieved early in the project. At the same time it could prove useful to let SPI or SPI(t) influence the performance factor - for just a small fraction. This is the case when the project shows a significant delay which most likely has a small impact on the actual cost.

In order to **forecast the duration** of the project, a performance factor equal to one outperforms the other performance factors, which confirms the value of the original schedule in the construction industry. Generally, the duration of the different activities, also including those at the end of the project, may be estimated very well at project initiation.

In addition, this study confirms the literature where it is suggested that the Earned Schedule duration forecasting method performs generally better than the Earned Duration and Planned Value method.

Re-baselining

The method of re-baselining has been the subject of serious discussions among EVM practitioners. The key questions are whether it is worth the effort to re-baseline and if this would provide better estimates. Although literature has attempted to give an answer when re-baselining is allowed by providing some rules and recommendations, not much empirical testing has been done until now. The present study did some innovative research by comparing the results of the EVM methodology on both the original and the re-baselined version of the same projects. By doing so, the added value of re-baselining could be assessed. Although the method of re-baselining was only executed on three projects, its influence on the forecasting was unanimous. For both the cost and duration forecasting methods re-baselining triggered a serious **decrease in the forecasting error**. This finding may be of great importance to EVM practitioners. Not only does this mean that the forecasting methods converge towards the final result, it also enables project managers who are confronted with uncertainty regarding which forecasting method to use, to achieve reliable forecasts.

It can be assumed that when experienced EVM practitioners have a good view on the future course of the project and the uncertainty induced, they might be able to differentiate between more and less suitable forecasting methods. Hence, this will result in even more accurate forecasts for the specific project. In order to achieve this goal, a thorough training on when to use which method is recommended.

When re-baselining is done, the use of appropriate forecasting methods is less clear compared to the performance based on the original baseline. Here the input of the project manager is crucial.

The results concerning **cost forecasting** after re-baselining are rather ambiguous. Although the CPI on average achieves stability earlier on in the project, the forecasting methods which rely on the CPI as performance factor, have to give in on performance. The performance factors relying on SPI(t) on the other hand, achieve better results when combined with a performance factor equal to one.

Regarding the performance of **duration forecasting** methods, re-baselining does not affect the preference for a performance factor of one, although it does create a notable difference in the performance of the earned schedule method in favor to the earned duration method.

In summary, it can be stated that re-baselining has a positive impact on forecasting in general. After re-baselining a significant decrease in forecasting error was observed for both cost and duration forecasting methods. This is good news for projects which have to cope with huge risks and uncertainties. In this kind of situations, it is important to have converging results from the sensitivity analysis, which results in more reliable forecasts. Although this convergence takes place, it may occur that re-baselining makes the best forecasting methods deviate more from the final outcome than prior to re-baselining. Therefore, re-baselining should be applied with caution because re-baselining will prevent the performance indicators to reflect the performance that was achieved before a new baseline was compiled. Hence, crucial data on past performance is lost.

Project characteristics

The present research investigated the impact of different project characteristics in relation to their influence on earned value predictors and EVM in general.

One of these characteristics is the p-factor, a dynamic schedule adherence measure, which is supposed to improve forecasts by taking the increase in risk of rework into account due to not following the schedule. The sample that was studied here had an overall high p-factor. Therefore, it was impossible to draw any strong conclusion related to this characteristic.

Another factor which was recently found to influence the duration forecast accuracy is the Serial-Parallel indicator. This indicator is supposed to influence the forecast effectiveness of duration forecast. Projects containing more serial activities are supposed to provide more accurate results. However, in this study no difference was found between the projects more resembling the serial and projects which are characterized by a rather parallel structure.

A third project characteristic, the length of the project, was also checked for its influence on CPI stability. In this study, a clear inverse relationship was found between both parameters. The longer a project lasts, the sooner (in percentage completed) CPI stability is achieved. This is in accordance with the suggested relationship in literature.

Implementation

While processing the data needed to evaluate the projects, some key insights were obtained which are useful for further implementation of the EVM methodology on construction projects. The four projects, which were approached from the project organizational point of view of four different construction companies, revealed a lot of similarities on how data was gathered. The most important findings are those related to how data could be collected in order to be valuable for the EVM methodology.

To join a tender, an estimate of the budget and schedule has to be set up. Therefore, calculations have to be made concerning the cost of the different activities which are scheduled. Once the public tender is won, a general observation was done that the information that is inherent in this original estimate is soon abandoned. Once the project starts, two separate systems are active to follow up on schedule and costs. This is done because both dimensions have a different Work Breakdown Structure (WBS). Although it might seem easier to follow up costs based on a separate WBS, this only leads to incapability of intervening in the course of the project. Besides, the information that can integrate both systems is present in the original estimates by which the tender was won. Using this information can therefore enable following up through an integrated system easily. This system requires both the schedule and the costs to use one and the same WBS.

To make the implementation of EVM a complete success, responsibilities should be clearly assigned to the members of the project team / organization. This can be done by composing an Organizational Breakdown Structure (OBS) and a Responsibility assignment matrix (RACI chart). Furthermore, looking for overlap between both WBS and OBS can help the process of composing the RACI chart.

Summary

In this study, empirical evidence is presented for most of the theories treated in literature concerning the EVM methodology. In addition, the study reached interesting findings concerning whether or not project managers should re-baseline. Given that no similar studies were found in literature, further research in both the domain of re-baselining and the performance of EVM in the construction sector is strongly encouraged.

Furthermore, it can be concluded that the EVM methodology definitely helps project managers control construction projects by providing accurate forecasts and early warning signals. All necessary information to implement this methodology is available in most construction projects. This information just has to be employed to integrate both schedule and costs in one WBS. Other requirements for using EVM are to have a clearly defined scope and to have the support of the organization which enables allocation of responsibilities.

The implementation of the EVM methodology on construction projects demands some effort and short-term yield is not obvious. However, this effort only needs to be done at the beginning of the project and will eventually prove valuable throughout the course of the project. This added value consists of providing early warning signals for project managers and in the long run, employing EVM will help to a gain better view on the progress of the project's performance. EVM provides project managers with quantifiable and tangible data on whether the project is performing according to plan or not. This quantifiable data can subsequently be extrapolated throughout the portfolio of projects and will allow better estimates for new projects. The experience, gained by implementing EVM will also enable PMs to apply the most appropriate forecasting methods which will eventually lead to even better results. Nevertheless, appropriate training, and organizational support is required to reach these objectives.

Conclusively, we strongly believe that the EVM methodology could have helped the studied projects in achieving a better understanding of the project performance. Moreover, when EVM would be incorporated as a general project management tool by construction companies and its methodology would be understood well by project managers, it could definitely serve as a powerful tool to follow up all types of construction projects.

References

Abba W. (2006). “Understanding program resource management through Earned Value Analysi.” PMI WDC Tool Time, July 18

Alvarado, Carlos M., Robert P. Silverman, and David S. Wilson (2004, June). “Assessing the Performance of Construction Projects: Implementing Earned Value Management at the General Services Administration.” *Journal of Facilities Management* 3/1: 92-105.

Anbari, Frank T. (2001). “Applications and Extensions to the Earned Value Analysis Method.” Proceedings of the Project Management Institute 2001 Seminars & Symposium.

Anbari, Frank T. (2003, December). “Earned Value Project Management Method and Extensions.”*Project Management Journal* 34.4: 12-23.

Antvik, Sven (1998, October). "Earned Value Management (EVM) - A 200Year Perspective." *Proceedings*. Project Management Institute.

Barr, Zeev (1996, December). "Earned Value Analysis: A Cast Study." PM Network, pp. 31-37.

Caletka, Anthony F., CCM (2009) “Managing Construction Projects: *Have you taken your project's pulse lately? Project Health Checks.” Lorman Education Services, Rochester, NY.*

Christensen, David S. and Scott Heise (1993, Spring). Cost Performance Index Stability *National Contract Management Journal 25:* 7-15.

Christensen, David S. and David Rees (2002, Winter). Is the Cumulative CPI-based EAC a Lower Bound to Final Cost on Post-A12 Contracts? *Journal of Cost Analysis and Management,* pp. 55-65.

Custer, Keith, PE (2008, December). “Ten Things You Need to know About Earned Value Management.” Custer Consultants Inc.

Custer, Keith, PE (2009). “The Seven Deadly Myths of Earned Value Methods in Project Management.” Custer Consultants Inc.

Durrenberger, Mark (2003). “An Earned Value Tutorial.” Oak Associates, Inc.

Fleming, Quentin W. and Joel M. Koppelman (1996). "Earned Value Project Management." *Project.* Association for Project Management. United Kingdom.

Fleming, Quentin W. and Joel M. Koppelman (2002, March-April). "Earned Value Management: Mitigating the Risks Associated with Construction Projects." *Program Manager:* 90-95.

Fleming, Quentin W. and Joel M. Koppelman (2004, Spring). If EVM is so Good, Why Isn't it used on all Projects? *The Measurable News, 5 pages.*

Fleming, Quentin W. and Joel M. Koppelman (2005). *Earned Value Project Management,* 3rd edition. Newton Square, PA: Project Management Institute (PMI). ISBN 1-93069989-1.

Henderson, Kym and O. Zwikael. (2008, April). "Does Project Performance Exist? A Re-examination of CPI and Evaluation of SPI (t) stability." C*rossTalk - The Journal of Defense Software Engineering*21:7-13.

Jacob, D. S. (2003, March). "Forecasting Project Schedule Completion With Earned Value Metrics." *The Measurable News:* p. 1,7-9.

Kim, EunHong, Wells Jr., William G. and Duffey, Michael R. (2003). “A model for effective implementation of Earned Value Management methodology.” International Journal of Project Management 21:375-382

Lewis, J. P. (2001). “Project Planning, Scheduling and Control: A hands-on guide to bringing projects in on time and on budget. 3rd Edition. New York, NY: McGraw-Hill.

Lipke, Walter H (2003, Summer). "Schedule is Different." *The Measurable News.*

Lipke, Walter H. (2004, Winter). "Connecting Earned Value to the Schedule." *The Measurable News*, pp. 1,6-16 and *Cross Talk*, *the Journal of Defense Software Engineering* (Jun 2005).

Lipke, Walter H. (2005, Summer). "A Re-Examination of Project Outcome Prediction ...Using Earned Value Management Methods." *The Measurable News*, pp. 14 - 26.

Lipke, Walt (2009). "Project Duration Forecasting." *Cross Talk*.

Lipke, Walt, Dr. Zwikael, K. Henderson and Dr. Anbari (2009, May). "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: 400-407.

Marshall, Robert A (2005, October). "The Case for Earned Value Management with Fixed-Price Contracts." *Contract Management*, pp. 30-34.

Marshall, Robert A. (2007, September). "The contribution of earned value management to project success on contracted efforts: A quantitative statistics approach within the population of experienced practitioners." *Journal of Contract Management.*

Meredith, J. R. and Mantel, S. J. (2000). "Project Management: A Managerial Approach. Wiley New York.

Payne, Kirk I (1990, September). *An Investigation of the Stability of the Cost Performance Index*. MS Thesis, Air Force Institute of Technology, Wright Patterson AFB, Ohio.

Prentice, J.-P., CCE. (2003). "Earned Value in the Construction and Facilities Maintenance Environments." In *Transactions of AACE International: Vol. 2003. CSC.17*,pp. 1-4. Solanki, Piyush (2009). "Earned Value Management: Integrated View of Cost and Schedule Performance." Global India Publications. pp. 65

Valle, Jose Angelo and Soares, Carlos Alberto Pereira. (2008) "The Use of Earned Value Analysis (EVA) in the Cost Management of Construction Projects." IBEC, Rio de Janiero, Brazil

Vanhoucke Mario, Vandevoorde Stephan (2007). "A Simulation and Evaluation of Earned Value Metrics to Forecast Project Duration." *Journal of the Operational Research Society*.

Vanhoucke Mario, Vandevoorde Stephan (2008, Winter) "Measuring the Accuracy of Earned Value/ Earned Schedule Forecasting Predictors." *The Measurable News:* 26-30.

Vanhoucke Mario, Vandevoorde Stephan (2009, February) "Forecasting a Project's Duration under Various Topological Structures." *The Measurable News 1 :26-30.*

Vanhoucke Mario. (2010). "Measuring Time, Improving Project Performance Using Earned Value Management." Springer. ISBN: 978-1-4419-1013-4.

Vargas, Ricardo Viana (2003). "Earned Value Analysis in the Control of Projects: Success of Failure?" *The Measurable News and Transactions of AACE International*.

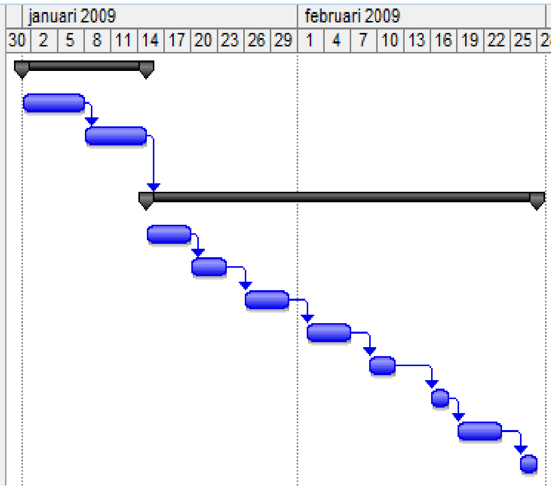
Winston, J. Ledet and Maroulis, Spiro J. (1998, Ocotober) "Improving Project Performance with Simulation and Practice." Project Management Institute, 1998 Seminars & Symposium.

Appendices

Appendix I: Cost distribution example

The project comprises the construction of a basement. It is planned to have a duration of 2 months and has a planned cost of €20.000. The following data was provided: a plan, monthly follow-up data and a general cost estimation of the main activities in the project.

Activity	Duration	Start date	End date
Preparatory work	**10 dagen**	**don 1/01/09**	**woe 14/01/09**
Soil work	5 dagen	don 1/01/09	woe 7/01/09
Sewerage system	5 dagen	don 8/01/09	woe 14/01/09
Basement	**32 dagen**	**don 15/01/09**	**vri 27/02/09**
Removing earth	3 dagen	don 15/01/09	maa 19/01/09
Concrete poles	4 dagen	din 20/01/09	vri 23/01/09
Armouring bottom plate	5 dagen	maa 26/01/09	vri 30/01/09
Sewerage system inside bottom plate	5 dagen	maa 2/02/09	vri 6/02/09
Concrete bottom plate	3 dagen	maa 9/02/09	woe 11/02/09
Concrete walls	2 dagen	maa 16/02/09	din 17/02/09
Armouring upper plate	3 dagen	don 19/02/09	maa 23/02/09
Concrete upper plate	2 dagen	don 26/02/09	vri 27/02/09



+

	Jan 09	Feb 09
Soil work	**€2.000**	**€0**
- Wages	€1.000	€0
- Materials	€1.000	€0
Concrete work	**€3.000**	**€3.500**
- Wages	€500	€1.000
- Materials	€2.500	€2.500
Armouring work	**€4.000**	**€2.500**
- Wages	€1.000	€500
- Materials	€3.000	€2.000
Sewerage work	**€3.000**	**€2.000**
- Wages	€1.000	€500
- Materials	€2.000	€1.500
Total Budget	**€12.000**	**€8.000**

+

	Budget Cost
Preparatory work	4.000
Basement	16.000

Figure 18: Cost distribution example

Combining this data, the following distribution of costs can be deduced:

	Cost	Order
Preparatory work		
Soil work	€1.000	(2)
Sewerage system	€3.000	(1)
Basement		
Removing earth	€1.000	(3)
Concrete poles	€3.000	(1)
Armouring bottom plate	€4.000	(1)
Sewerage system inside bottom plate	€2.000	(1)
Concrete bottom plate	€1.500	(4)
Concrete walls	€1.000	(4)
Armouring upper plate	€2.500	(1)
Concrete upper plate	€1.000	(4)

Table 25: Cost distribution

In a first step, the activities on the plan are marked per month. These activities are compared with the follow-up data per month and a cost can be assigned to all stand alone activities. For example there is only one sewerage work in January: "sewerage system". The entire cost of €3.000 can be assigned to this activity. (1)

Second another cost can now be calculated using the cost estimation of a group of activities. For example the cost for soil work can be calculated by subtracting the cost of the sewerage system from the general cost of the preparatory work: €4.000 - €3.000 = €1.000. (2)

With this cost information, certain costs of similar activities that are executed in the same period can be assigned. The cost of removing earth for example can be calculated by subtracting the cost of soil work from the general soil work activity in January: €2.000 - €1.000 = 1.000. (3)

Fourth, for some specific activities too few information is available to assign a cost to it. Then, if the content of the activities is unclear, information was asked to the project manager. If not, a distribution was made based on the duration of the activities. In the example three concrete works are done in February for a total of €3.500. "Concrete bottom plate" has a duration of three days while "concrete walls" and "concrete upper plate" only require two days. This means that in total for the entire concrete work seven days are needed. The specific cost per activity can be calculated using the Rule of Three:

7 days = €3.500 ⇔ 1 day = €500 ⇔ 3 days = €1.500 and 2 days = €1.000. (4)

Appendix II: Stability results per project

Table 26 shows for the different projects when stability is achieved, as percentage completed. The Fluxys project for example achieved CPI stability already when the project was only three percent completed. Both the results of the original and re-baselined schedule are given. As the Louis De Waele and Soetaert project did not incorporate re-baselining during the project, no re-baselined data is available.

	CPI stability		**SPI stability**		**SPI(t) stability**	
	Original	Rebaselined	Original	Rebaselined	Original	Rebaselined
Fluxys	3%	3%	44%	38%	79%	84%
Jan De Nul	11%	11%	38%	11%	49%	27%
Louis De Waele	8%	/	90%	/	90%	/
Soetaert	29%	/	14%	/	14%	/
Strabag	29%	15%	81%	38%	49%	15%
< 20% stable (#)	**3/5**	**3/3**	**1/5**	**1/3**	**1/5**	**1/3**
< 20% stable (#)	**60%**	**100%**	**20%**	**33%**	**20%**	**33%**

Table 26: Stability results

Appendix III: Statistical results

1. Indices stability for the original and re-baselined schedules (hypothesises 7-9)

The Wilcoxon ranked sign test was used to test whether re-baselining has a positive influence on indices stability. Table 27 and 28 give an overview of the results. As the test aimed to discover a positive influence, the significance values in table Y should be divided by two. Nevertheless no significance can be detected for neither of the three indices as the values are all higher than 0,05.

Ranks

		N	Mean Rank	Sum of Ranks
CPI_RB - CPI_stability	Negative Ranks	1[a]	1,00	1,00
	Positive Ranks	0[b]	,00	,00
	Ties	2[c]		
	Total	3		
SPI_RB - SPI_stability	Negative Ranks	3[d]	2,00	6,00
	Positive Ranks	0[e]	,00	,00
	Ties	0[f]		
	Total	3		
SPIt_RB - SPIt_stability	Negative Ranks	2[g]	2,50	5,00
	Positive Ranks	1[h]	1,00	1,00
	Ties	0[i]		
	Total	3		

Table 27: Results hypothesis (7-9)a

Test Statistics[b]

	CPI_RB - CPI_stability	SPI_RB - SPI_stability	SPIt_RB - SPIt_stability
Z	-1,000[a]	-1,604[a]	-1,069[a]
Asymp. Sig. (2-tailed)	,317	,109	,285

a. Based on positive ranks.

b. Wilcoxon Signed Ranks Test

Table 28: Results hypothesis (7-9)b

2. Comparison of the different cost forecasting methods (hypothesis 10)

The Friedman test was used to test whether the different cost forecasting methods perform on average equally good. From table 29 can be seen that a significant difference existed between the different methods. A post-hoc analysis with the Wilcoxon ranked signs test was used to test for significant difference between two methods.

Test Statistics[a]

N	5
Chi-Square	16,800
df	7
Asymp. Sig.	,019

a. Friedman Test

Table 29: Results hypothesis 10a

Table 30 and 31 show a significant difference in average rank between EAC_6 and EAC_8/EAC_7. Also significant but not presented here is the difference between EAC_4 and EAC_2/EAC_7/EAC_8.

Test Statistics[b]

	EAC6score - EAC8score
Z	-2,032[a]
Asymp. Sig. (2-tailed)	,042

a. Based on negative ranks.

b. Wilcoxon Signed Ranks Test

Table 30: Results hypothesis 10b

Test Statistics[b]

	EAC6score - EAC7score
Z	-2,023[a]
Asymp. Sig. (2-tailed)	,043

a. Based on negative ranks.

b. Wilcoxon Signed Ranks Test

Table 31: Results hypothesis 10c

3. Comparison of the different duration forecasting methods (hypothesis 11)

Similar to the cost forecasting comparison, the different duration foresting methods are compared with the Friedman test. Table 32 and 33 show the results of the Friedman test for the entire sample and when the Fluxys project is excluded.

Test Statistics[a]

N	5
Chi-Square	12,575
df	8
Asymp. Sig.	,127

a. Friedman Test

Table 32: Results hypothesis 11a

Test Statistics[a]

N	4
Chi-Square	22,159
df	8
Asymp. Sig.	,005

a. Friedman Test

Table 33: Results hypothesis 11b

The post-hoc analysis for the four project sample is again done with the Wilcoxon signed ranks test. It can be seen that for all methods a performance factor equal to one gives significant the better forecasting estimates than a performance factor equal to the SPI. The comparison between $EAC(t)_{X3}$ and $EAC(t)_{X1}$ is not included but showed similar significance.

Test Statistics[b]

	EACtpv2score - EACtpv1score
Z	-1,841[a]
Asymp. Sig. (2-tailed)	,066

a. Based on negative ranks.

b. Wilcoxon Signed Ranks Test

Table 34: Results hypothesis11c

Test Statistics[b]

	EACted2score - EACted1score
Z	-1,841[a]
Asymp. Sig. (2-tailed)	,066

a. Based on negative ranks.

b. Wilcoxon Signed Ranks Test

Table 35: Results hypothesis 11d

Test Statistics[b]

	EACtes2score - EACtes1score
Z	-1,841[a]
Asymp. Sig. (2-tailed)	,066

a. Based on negative ranks.

b. Wilcoxon Signed Ranks Test

Table 36: Results hypothesis 11e

4. The influence of the p-factor on the average forecasting accuracy (hypothesis 12)

Linear regression was used to test a linear relationship between the average p-factor and the sum of the average forecasting accuracy of both the cost and duration methods. The results are presented in tables 37 and 38.

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
,940	,883	,825	,016

The independent variable is Avg_P.

Table 37: Results hypothesis 12a

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	,004	1	,004	15,152	,060
Residual	,001	2	,000		
Total	,004	3			

The independent variable is Avg_P.

Table 38: Results hypothesis 12b

The assumption is made that the residuals follow the normal distribution. This is tested with the Kolmogorov-Smirnov test. From table 39 can be seen that no normal distribution can be assumed. Therefore no statistical value can be ascribed to the linear regression results.

One-Sample Kolmogorov-Smirnov Test

		Residuals
N		4
Normal Parameters[a]	Mean	,0000000
	Std. Deviation	,01291923
Most Extreme Differences	Absolute	,232
	Positive	,232
	Negative	-,206
Kolmogorov-Smirnov Z		,465
Asymp. Sig. (2-tailed)		,982

a. Test distribution is Normal.

Table 39: Results hypothesis 12c

5. The influence of the length of the project on CPI stability (hypothesis 14)

Again linear regression was used to test the relation between the length of a project and the moment when CPI stability was found. The results are presented in tables 40 and 41.

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
,690	,476	,301	,102

The independent variable is Length.

Table 40: Results hypothesis 14a

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	,028	1	,028	2,721	,198
Residual	,031	3	,010		
Total	,060	4			

The independent variable is Length.

Table 41: Results hypothesis 14b

The assumption that the residuals are normally distributed should again be verified. Table 42 shows that no normal distribution can be assumed. Therefore no statistical value can be ascribed to the linear regression results.

One-Sample Kolmogorov-Smirnov Test

		Residuals
N		5
Normal Parameters[a]	Mean	,0000000
	Std. Deviation	,08839565
Most Extreme Differences	Absolute	,183
	Positive	,183
	Negative	-,147
Kolmogorov-Smirnov Z		,409
Asymp. Sig. (2-tailed)		,996

a. Test distribution is Normal.

Table 42: Results hypothesis 14c

6. The influence of the length of the projects on SPI and SPI(t) stability

Similar as with CPI stability, graphs were made that represent the relationship between the length of the projects and SPI/SPI(t) stability. Figure 19 and 20 give an overview of the results. From neither of the graphs, a linear relationship can be noticed.

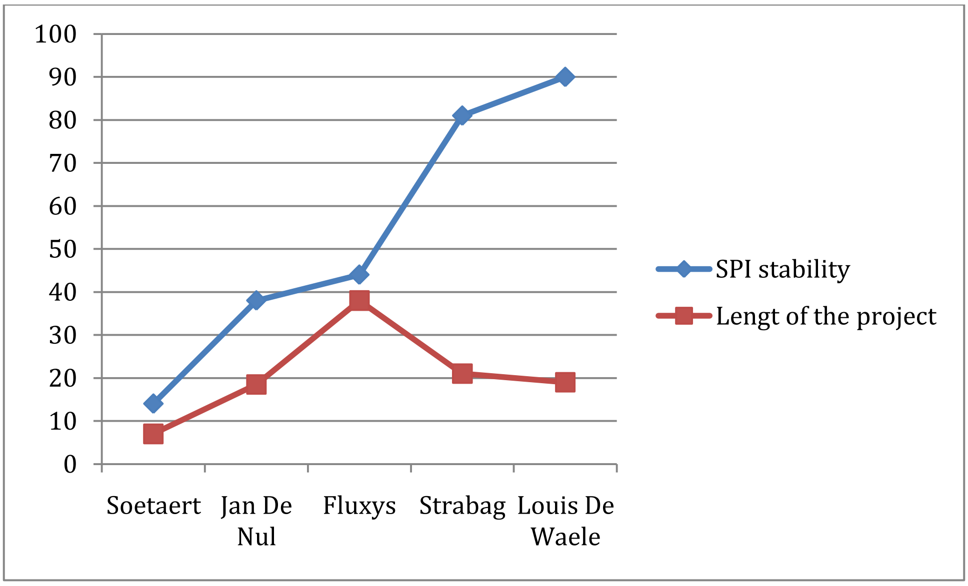


Figure 19: SPI stability compared to the length of the project

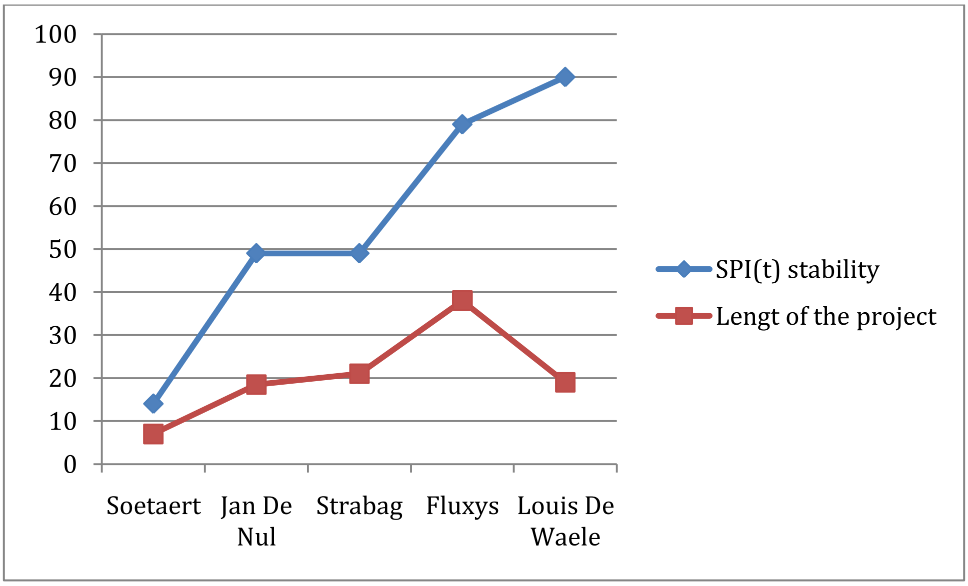


Figure 20: SPI(t) stability compared to the length of the project