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STABILITY OF EARNED VALUE MANAGEMENT

Do project characteristics influence the stability moment of the COST AND SCHEDULE PERFORMANCE INDEX

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ABSTRACT

Stability of the Cost Performance Index (CPI) and Schedule Performance Index ($SPI_{(t)}$) refers to the moment in the project life cycle at which the CPI and $SPI_{(t)}$ are accurate and constant. For a project manager a reliable CPI and $SPI_{(t)}$ is essential for taking corrective actions in time to keep the project on budget, planning and scope.
The focus of this paper lies on identifying project characteristics which influence this moment of CPI and $SPI_{(t)}$ in the project life cycle. Both existing theories from earlier academic research and newly identified project characteristics are tested by using empirical data from nine projects executed by an engineering and consultancy company in the Netherlands. It is found that some project characteristics influence the moment of CPI and $SPI_{(t)}$ in the project lifecycle whereas other do not.
The results of this paper contribute to the body of knowledge on EVM and might provide valuable information to project managers who consider to use EVM in their projects.
The results of this research also point out new areas to explore the understanding of the stability of CPI and $SPI_{(t)}$.

1. Introduction

Uncertainties in projects cause risks resulting in deviation from the initial project plan *(Vanhoucke and Shtub, 2011)*. The challenge for a project manager is to uncover those deviations in time in order to take corrective actions to direct the project back on track. Therefore a project control system needs to be put in place. Earned Value Management *(EVM)* is one of the tools which might help a project manager to stay in control of his project *(Falco and Machiaroli, 1998)*. The following definition of EVM is used: "EVM is a method for integrating scope, schedule, and resources and for measuring project performance. It compares the amount of work that was planned with what was actually earned and with what was actually spent to determine if cost and schedule performance are as planned" *(Fleming and Koppelman, 2010)*.

The EVM parameters Actual Costs *(AC)*, Planned Value *(PV)* and Earned Value *(EV) (see* **Figure 1.A***)* are used for analyzing project performance. The performance measures are *(Fleming and Koppelman, 2010)*:

SV: Schedule Variance $(SV = EV\text{-}PV)$;
SPI: Schedule Performance Index $(SPI = \frac{EV}{PV})$;
CV: Cost Variance $(CV = EV\text{-}AC)$; and
CPI: Cost Performance Index $(CPI = \frac{EV}{AC})$.

The EVM metric SPI gets unreliable by the end of a late finish project. This is caused by the earned value which will eventually always meet the PV near the end of a project, regardless the project being over its deadline or not *(Corovic, 2006)*. To overcome this problem, Lipke *(2003)* developed the Earned Schedule *(ES)* with the indicators $SV_{(t)}$ and $SPI_{(t)}$.The ES method uses time based metrics instead of monetary metrics for project duration aspects. In **Figure 1.B** the concept of ES is visualised. The ES measures the moment when the Earned Value *(EV)* should have occurred according to the baseline *(PV)*: this is the moment *(in time)* where the PV equals the EV, called "the Earned Schedule" *(ES)*. With a known ES, the time-based indicators can be determined as follows:

$SV_{(t)}$ = ES-AT; and
$SPI_{(t)}$ = ES/AT.

In which AT stands for actual time. *(Lipke et al, 2009)*

The SPI and CPI can be interpreted as performance indices *(Anbari, 2003)*. It is a measure of conformance of the actual progress to the schedule. The EVM methodology is used by project managers to visualize the project status at various points in a project lifecycle. The status information helps project managers to control risks more effectively *(Kwak and Anbari, 2012)*. Therefore it is important to project managers that they can rely on EVM methods. This statement is also confirmed by Christensen and Payne *(1992)* and acknowledged by Lipke et al *(2003)* who claim that reliable indicators for costs *(CPI)* and schedule *($SPI_{(t)}$)* are necessary to guide a project. An uncertainty in the CPI and $SPI_{(t)}$ stability will generate risks allowing a project to deviate from the planning, without the project manager's knowledge *(Vanhoucke and Shtub, 2011)*. A sTable CPI or $SPI_{(t)}$ helps a project manager to determine what extra effort is needed to improve the efficiency of the remaining contractual effort *(Christensen and Payne, 1992)*. Henderson and Zwikael *(2008)* suggest that CPI stability is the evidence that the project management control systems are functioning properly.

Recent literature shows that the EVM predictability of project performance *(costs)* is sTable *(Kwak and Anbari, 2008)*, and these results are generally regarded as equally applicable to all project types *(Fleming and Koppelman, 2004)*. However, these studies have been performed on a database containing large projects executed by the US Department of Defense *(USDoD) (Lipke et al,*

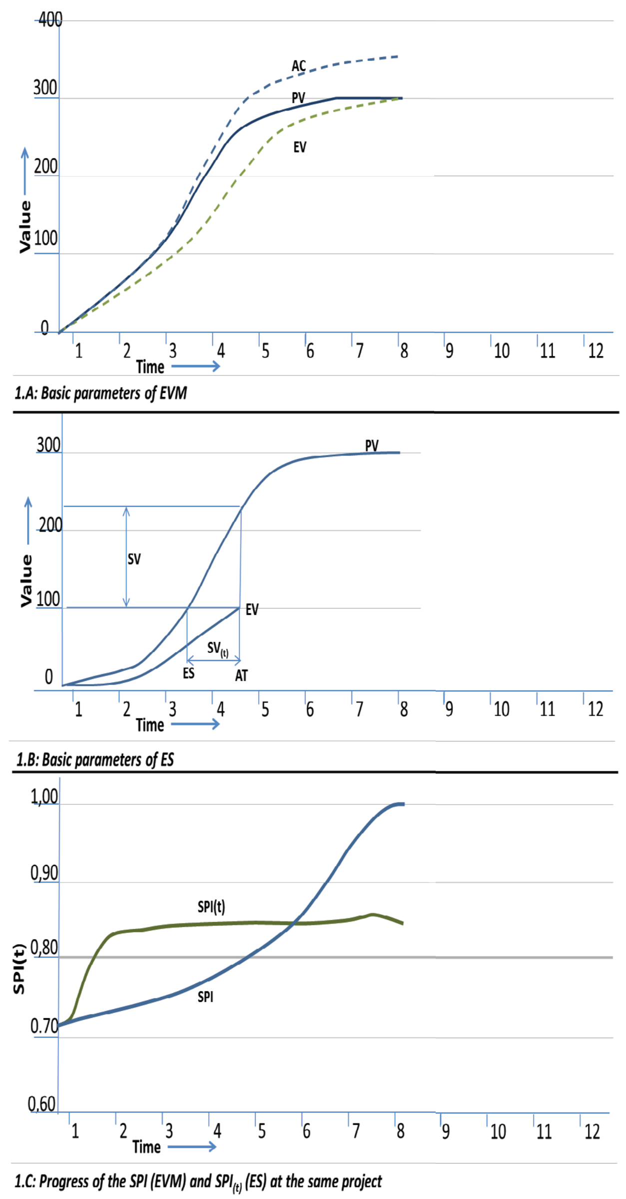

FIGURE 1: *The basic parameters of EVM and ES and difference between performance indicator SPI and $SPI_{(t)}$.*

2009), and as such the applicability of the findings for other types of projects can be questioned. Lipke *(2009)* mentioned that project managers of small projects seldom observe stability for the cost performance index *(CPI)*. He suggests that "without knowledge of the CPI stability behavior for smaller and non-USDoD projects, these managers have a limited liability to produce reliable forecasts of project cost outcome".

Czarnigowska *(2008)* studied the difference between the SPI and $SPI_{(t)}$. One of the research findings *(based on fictitious project data)* was that the SPI was moving towards the value 1 near the end of the project and did not have a "sTable moment" in the graph, whilst the $SPI_{(t)}$ was more reliable and showed stability during the project life cycle. These findings are also supported by other studies which include amongst others Vandervoorde and Vanhoucke *(2006)*, Vanhoucke and Vandervoorde *(2007)* and Lipke et al. *(2009)*, The ES fluctuations are much lower and more reliable than the EVM fluctuations of the SPI. This is shown in **Figure 1.C** *(taken from Czarnigowska, 2008)*.

The problem is that it is yet unknown how the performance indicators *(CPI and $SPI_{(t)}$)* of EVM perform within different project characteristics and what is the value of those metrics for project managers to help them taking corrective actions within projects.

This paper aims to answer the following question:

- How is the stability of CPI and SPI(t)) influenced by project characteristics?

The goal of this paper is to add to the knowledge on the applicability of Earned Value Management within different types of projects based on the characteristics. Results of this research can be used by both, project managers and academics. The structure of this paper is as follows: chapter 2 explains the stability of EVM and provides a review on the research of EVM stability. In chapter three the conceptual model and research methodology is shown The results are presented in chapter 4 and further discussed in chapter 5. The article finishes with a conclusion in chapter 6.

2. Stability in EVM

In this chapter an overview is given of previous research with a direct or indirect link to explaining the moment of CPI/$SPI_{(t)}$ stability in the project life cycle. Firstly the stability is described in paragraph 2.1. Paragraph 2.2 summarizes previous research on CPI/$SPI_{(t)}$ stability whereas paragraph 2.3 deals with project characteristics in relation to CPI/$SPI_{(t)}$ stability. A conclusion of the literature review is provided in paragraph 2.4.

2.1 Definition of stability

There are two methods used in recent research to define CPI and $SPI_{(t)}$ stability. Both methods define boundaries the CPI and $SPI_{(t)}$ are not allowed to exceed in order to be sTable. Both methods use the final CPI and $SPI_{(t)}$ value to determine the upper and lower bound. Whereas one method *(Payne, 1990; Christensen and Payne, 1992; Zwikael, Globerson and Raz, 2000)* uses a percentage *(10%)* to create the lower and upper bound, the other method uses an absolute number of 0.1 from which the lower and upper bound are derived *(Henderson and Zwikael, 2008; Lipke et al, 2009)*.

Boundaries with 10%:

$SPI_{(t)} = SPI_{(t)final} \pm (SPI_{(t)final} \times 0.1)$

$CPI = CPI_{final} \pm (CPI_{final} \times 0.1)$

Boundaries with value 0.1:

$SPI_{(t)} = SPI_{(t)final} \pm (0.1)$

$CPI = CPI_{final} \pm (0.1)$

Literature is inconclusive on which method is best to use nor does it contain pro or cons for each method. Both methods seem to be accepTable to be used.

2.2 Review on CPI and $SPI_{(t)}$ stability

2.2.1 Stability of CPI

Fleming and Koppelman *(2010)* suggest that CPI and $SPI_{(t)}$ stability can be reached within 20% of a project's completion time. However, over time different researches show various results. The first study on the stability of CPI was conducted by Payne *(1990)* using empirical data from 7 aircraft projects. He found that stability occurred after the 50% completion stage. Two years later, Christensen and Payne *(1992)* used a sample of 26 projects and concluded that the cumulative mean CPI does not change more than 10% compared to the projects final CPI at the 20% completion point of the project, thereby substantiating Fleming and Koppelman *(2010)*.

However, because the sample data used by Payne were rather small, it was difficult to extrapolate his findings to other services, programs, and contracts *(Christensen and Payne 1992)*. Therefore Christensen and Heise *(1993)* continued with Paynes *(1990)* research using more data. The research included 155 projects. The results of the research show that 99% of all 155 projects do reach CPI stability at least at the 50% completion point of the project. At the 20% completion point of the projects it turns out that 86% of the projects reached a sTable CPI.

Henderson and Zwikael *(2008)* used data from 26 different projects in their research. They concluded that, on average, the CPI stability was reached at the 60% completion point of the projects. In research by Popp *(1996)*, distribution charts were made of the final CPI and the current CPI at different completion stages of the examined projects. Popp's results do not show CPI stability at the 20% completion stage of a project, which contradicts Christensen and Payne's *(1992)* results, however underpins Henderson and Zwikael's *(2008)* research findings tha stability is found further on in the project.

Other research conducted by Lipke *et al (2009)* and Zwikael *et al (2000)* indicates that the stability of the CPI is reached after 50% of the project completion. This substantiates Popp's *(1996)* and Henderson and Zwikael's *(2008)* results. According to Zwikael *et al (2000)* "*CPI stability depends to a great extent on the quality of the original budget and on the ability of the project manager to correct deviations and to stick to the plan. These two factors vary widely across industries, companies, and even teams and individuals*".

2.2.2 Stability of the $SPI_{(t)}$

Research on the stability of the $SPI_{(t)}$ has not been widely conducted. The $SPI_{(t)}$ was proposed in 2003 by Lipke *(Lipke, 2003)*. However, prior to 2003 only the SPI existed. It was known that the SPI becomes unreliable after approximately 2/3 of the project life cycle. Therefore research on the stability of the SPI was not considered useful *(Lipke et al, 2009)*.

Henderson and Zwikael *(2008)* were the first to study the $SPI_{(t)}$ stability. They used 37 projects in their analysis. The results show a wide variety in the moment when the $SPI_{(t)}$ is sTable. The stability can even be achieved very late in the project life cycle, up to well past the 80% completion point. For 12 out of 37 projects the stability of the $SPI_{(t)}$ is reached in the 80% to 100% completion stage of the project life cycle.

Research conducted by Buyse and Vandenbussche *(2010)* included five projects in the construction industry. The SPI and $SPI_{(t)}$ stability was reached at the 90% completion stage of all projects. Some reasons they found for the late stability of the $SPI_{(t)}$ were:

- Slow start-up of the project due to architectural difficulties; and
- Additional work and rework caused by others near the end of the project.

The recent research have shown contradicting results on the moment in which CPI or $SPI_{(t)}$ stability is found. Although it does show that stability can be found at the 20% completion point of a project life cycle, this is not generally applicable to all projects since research does show various stability moments of the CPI or $SPI_{(t)}$. The reasons for these different results are still unclear. The literature does not explain why this is different. Reaching the stability of the CPI and $SPI_{(t)}$ in an early phase of a project is also dependent on how well the management control systems are functioning and on the ability of the project manager to correct deviations and to hold on to the plan *(Henderson and Zwikael, 2008)*. This suggests that the quality of the control management systems has a large influence on the moment that CPI and $SPI_{(t)}$ stability is reached in projects *(Azimi et al, 2011)*.

2.3 Project Characteristics influencing stability

2.3.1 Project size - duration

The use of EVM and ES has been discussed by numerous authors, especially in relation to the size of the project. Although Fleming and Koppelman *(2010)* assume that EVM is applicable to all kinds of projects and sTable CPI and SPI values can be reached as early as the 20% completion point, different authors suggest that this assumption is applicable to large projects only.

Buyse and Vandenbussche *(2010)* were able to show some relation between project duration and the stability moment of the CPI. A decrease in project duration leads to a later moment in a project life cycle where the CPI is sTable. These results support Lipke's statistical calculations *(Lipke, 2005)* that the moment of CPI or $SPI_{(t)}$ stability is related to the project's duration. He discusses the length of a project in relation to CPI stability. Lipke *(2005)* used a statistical approach in determining the minimum number of months needed in a project for the relationship **[$CPI_{final} - CPI_{20\%} \leq 0.1$]**. A minimum project duration of at least 6.7 years is needed. This means that small projects cannot predict the final costs with the same reliability as long duration projects at the 20% completion point. As such, Lipke *(2003)* claims that the relationship **[$CPI_{final} - CPI_{20\%} \leq 0.1$]** has its limitations with respect to project duration. In his calculations, Lipke took the number of observations in a project into account *(number of observations per month)*. He suggests the idea that small projects require a higher intensity of project performance measuring *(observations)*. This is also acknowledged by Custer *(2008)*, who says an increased reporting cycle is required when projects get smaller.

The report of larger fluctuations of the CPI and $SPI_{(t)}$ in small projects, and consequently a later moment of stability, can be explained by Down Time *(periods when no work is scheduled)* or Stop Work *(periods during the project execution where management has paused the project activities)*. For large projects stop work or down time occur often in activities which are relatively small compared to the total of activities in a project. Therefore, large projects produce no significant differences in the CPI-values. However, in small projects, stop work and down time may distort the ES or EVM indicators and forecasting, possibly by enough to affect decisions made by management *(Lipke, 2011)*.

2.3.2 Project size - budget

The budget is the total of the allocated costs to each activity in a project. Although research focuses on the relationship between project duration and SPI and CPI stability, the budget is often used in discussions whether EVM is beneficial to apply in small, budget limited, projects *(Cioffi, 2005)*. Buyse and Vandenbussche *(2010)* discuss three reasons why project managers might not apply EVM to small projects:

- Project managers believe EVM creates lots of extra work;
- Fear of having to change the organization of the company or project team when implementing EVM; or
- Project managers assume project costs will rise due to the need for new software packages (Christensen, 1998).

In contradiction to the project duration, no literature was found that discusses project budget in relation to EVM stability.

2.3.3 Team size

According to Hoegl *(2005)*, team size matters. Smaller teams seem to perform more efficiently. It is suggested that smaller teams have a more direct and more efficient intrateam manner of communication, a greater effort is made by all team members and there is a better utilization of all team members. The larger the team, the more difficult the sharing and coordination of technical information becomes *(Hoegl, 2005)*. It has been suggested that team building might overcome these negative characteristics of large project teams. However, Zwikael *(2010)* showed that there is little relationship between team building and project success. In his research, he concluded that the project duration moderates the relationship between team development and project success *(Zwikael, 2010)*. This could possibly imply that in long duration projects the control becomes more efficient thereby creating a sTable CPI or $SPI_{(t)}$, whereas in short duration projects this process does not occur. No literature has been found that supports or proves this hypothesis.

2.3.4 Serial-Parallel factor

Project characteristics can also be defined in terms of their topological structure. Vanhoucke *(2012)* has reviewed different literature discussing the topological structure in relation to the quality of the constructed planning and the risks for delays. One of the relevant topological structures is the serial-parallel factor.

The serial-parallel factor is introduced by Vanhoucke *(2008)* and is based on the *I*2 indicator originally developed by Tavares *(1999, 2002)*. The SP factor measures the closeness of project activities to a serial or parallel network. The SP factor values vary from 0 to 1. A SP of "0" indicates a project where all activities are organized parallel to one another and an SP factor of "1" indicates a project where all activities are planned serially. Vanhoucke and Vandevoorde *(2007)* have shown that the SP factor plays an important role in the accuracy of project duration prediction using EVM. Based on a simulation with 4100 generated projects, it has been shown *(that projects which are close to a parallel network are best controlled by Schedule Risk Analysis (SRA)*: "*is a simulation technique to reveal the critical components of a project that likely have the biggest impact on the project objective*", Vanhoucke 2012). When activities are planned parallel to one another, there is a higher risk that non-critical path activities delay the project. Therefore, a bottom-up control approach is needed to control each activity at the activity level *(SRA)*. Contrary to projects that run parallel, a project with a serial topological structure can be controlled top-down *(using EVM)*. A delay in an activity in a fully serially organized project is always a critical-path activity. Therefore, EVM provides reliable warning signals in a project with a serial organization *(Vanhoucke, 2012)*. This is also confirmed in Vanhoucke *(2011)* which shows that top-down project tracking *(like EVM)* is highly efficient for networks with a serial activity structure.

In addition to the fictitious project data, Vanhoucke *(2010)* used empirical data from 48 projects. The results using empirical data show the same pattern as the research using fictitious data, thereby allowing Vanhoucke to extrapolate his research results based on fictitious data to real project data. Some of the conclusions are:

- in a serial project network structure the probability to mask errors by measuring project performance on a high Work Breakdown Structure (WBS) level decreases;
- when a project has many parallel activities, the EVM method should be used in conjunction with SRA.

These results show that a careful combination of top-down and bottom-up approaches is desired in projects depending on the SP-factor. This is confirmed by Alshaer *(2013)*, Fleming and Koppelman, 2002, Goodman *(2010)*, Pajeres and López-Paredes *(2011)*, Czarnigowska *(2008)*, and Henderson *(2005)*, who acknowledge the importance of keeping control of critical path activities, which might be overlooked in parallel organized projects.

Vanhoucke's research focused on the reliability of project duration forecasting. He did not study the influence of the SP-factor on the stability of the CPI and $SPI_{(t)}$. However, because there is a direct relation between the SP-factor and the reliability of project duration forecasting using EVM, it is expected that there is a relation between the CPI and $SPI_{(t)}$ stability since the project duration forecasting methods rely heavily on the $SPI_{(t)}$.

2.3.5 S-curve steepness and project complexity

When the cumulative allocated costs for each activity in a planning are graphically presented over time, an S-curve will often appear. According to Goodman *(2010)* the steepness of the S-curve is often associated with complex projects. Indeed, when the S-curve steepness in the middle increases, more activities are executed simultaneously or in a fast succeeding manner. There is no additional literature to be found which substantiates the relation between project complexity and the S-curve shape mentioned by Goodman *(2010)*, however a link could be made to "structural" complexity and how this might influence the stepness of the S-curve. Koppejan et al *(2010)* identified two categories of project complexity: **[1]** structural complexity and **[2]** dynamic complexity. Structural complexity refers to systems and projects that consist of a larger number of interacting components. Dynamic complexity deals with the project environment and interactions which are subject to change. Dynamic complexity results in unpredictability, uncertainty and emergent behavior. In managing projects, structural complex projects are best managed by the predict and control perspective on project management *(for example EVM)*. This approach is designed to control the project with analysis to overcome uncertainty and complexity. In contrast, dynamic complex projects are best managed by prepare and commit perspective *(for example process management)*. The focus is less on the end of the project, but on dealing with uncertainty by sharing *(it is a shared task)* project information and risks. It very much deals with learning curves, scope changes and changes in the project's environment *(Koppejan et al, 2010)*.

Project complexity is influenced by varying budgetary, scheduling and safety constraints in science and technology projects *(Kwak and Anbari, 2012)*. The benefits of EVM in structural complex projects is that project constraints can be managed more effectively *(Kwak and Anbari, 2012)*. As such Kwak and Anbari *(2012)* promote the use of EVM in structurally complex projects. However according to Vanhoucke *(2010)*, EVM can be questioned when used in very complex projects. EVM is based on the assumption that all project activities and the way they relate to each other are known in advance. If complex projects are characterized by the fact that not all activities and how they relate to each other are known in advance, the basis of EVM is at risk. This implies that EVM is not suiTable for structural complex projects. In "*letters to the editor*" *(Harvard Business Review*[1]*)* a complex project is regarded as a project which has an iterative character when performing activities. The iterative character is largely determined by the technical sophistication of the project's end product *(in other words: the scope)*. Technically complex projects do not consist of a straight line of discrete activities with clear beginnings and endings. Indeed, technical projects require an iterative process. Cycles of rework can therefore blur the moment when the tasks are really finished. This is also acknowledged by Vanhoucke *(2010)* who claims that the accuracy of EVM metrics can be biased due to cycles of rework.

In complex projects the manager should not focus on the use of EVM alone *(Koppjean et al, 2010)*, because unreliable results can be expected

1 Last accessed on 22 February 2013: http://hbr.org/2003/12/letters-to-the-editor/ar/1

that affect the baseline of EVM *(also acknowledged by Vanhoucke, 2010)*. In the management of complex projects, management should balance controlling and flexible approaches. It is suggested that EVM has limited use in highly complex projects which are characterized by iterative processes. Research by Buyse and Vandenbussche *(2010)* corroborates this. They postulate that the rework is one of the possible explanations in reaching $SPI_{(t)}$ stability in a late phase of a project.

Project complexity can be referred to as structural complexity *(the project structure)* or dynamic complexity *(the project context)*. Concerning structural complexity, different opinions are to be found on whether EVM is a suiTable tool to control projects. It has been suggested in the literature that complexity is related to the S-curve shape of the project's planned value. Hereby suggesting a steeper s-curve increases the number of activities that are executed simultaneously or in a fast succeeding manner and thereby related to structural *(the way activities are organized)* complexity. However little literature was found on this matter.

2.4 Conclusion literature review

Based on earlier studies it was generally believed that the CPI is sTable at the 20% completion point. However, these results are criticized because the project data used originated from a database which contained only data from very large USDoD projects and programmes. Subsequent research has shown that the generally believed 20% completion point for EVM stability does not apply to other projects *(non-USDoD)*. Research has shown that project duration influences the moment of CPI stability in a project. It is now generally believed that longer project duration leads to relatively earlier *(as the percentage of project completion)* CPI stability. A few studies have been undertaken on the stability of the SPI($t_{(t)}$) in projects since the development of ES. The research available and reviewed in this paper has shown that $SPI_{(t)}$ stability is reached as early as 20% to as late as 90% of the project life cycle *(Henderson and Zwikael, 2008)* which is in line with the results of Buyse and Vandenbussche results *(2010)*.

Although little research was found concerning the relation between CPI and $SPI_{(t)}$ stability and project characteristics, the review indicates some characteristics which might be considered:

- Project size (duration and costs);
- Project progress monitoring interval;
- Project team size;
- Parallel versus serial activities; and
- project complexity.

The listed project characteristics are not exhaustive, and other, characteristics that have been omitted from the list are likely to exist which may influence the stability of EVM. This literature review provides an overview of characteristics found in literature. Other possible characteristics are beyond the scope of this research.

3. Methodology

The review on stability in EVM *(chapter 2)* forms the basis of the conceptual research model. The research model is explained in paragraph 3.1. Subsequently the research approach and data collections justified in paragraph 3.2. In paragraph 3.3 the method used to test the hypothesis is explained.

3.1 Conceptual research design

The conceptual research design is presented in **Figure 2**. There are six independent variables distinguished which might explain the moment of CPI and $SPI_{(t)}$ stability *(dependent variables)*.

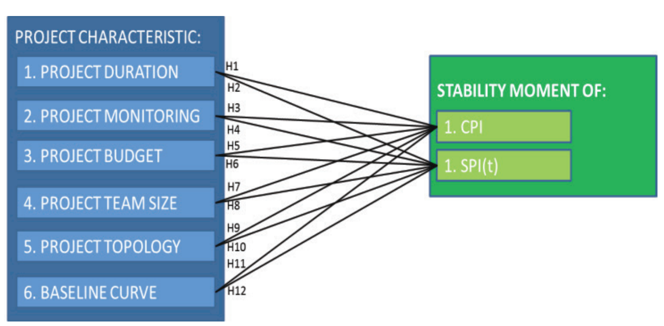

FIGURE 2: *the conceptual research design: the hypotheses.*

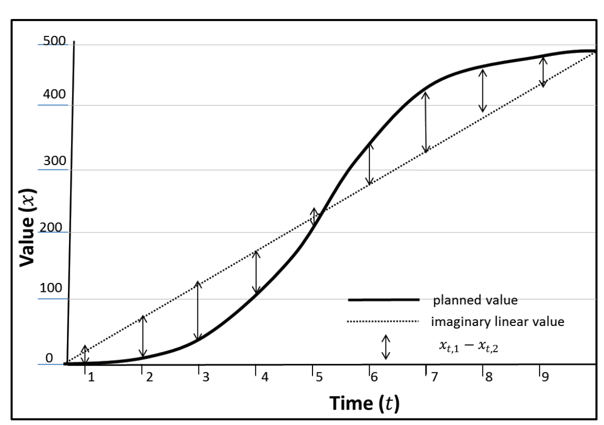

FIGURE 3: *the actual planned baseline against the "imaginary" linear value. Used to calculate the S-curve characteristics.*

In total, there are 12 hypotheses to be distinguished *(6*2)*, as illustrated in **Figure 2**. The testing of the hypotheses is further discussed in paragraph 3.2. The used variables in this research are explained next.

3.1.1 Determining project duration, monitoring, budget and team size

- The project duration is defined as the total of the months in which the project required to meet the planned value;
- The monitoring interval is expressed in percentages of the total project duration (project of 10 weeks, with a weekly project monitoring, as a project monitoring of 0.1 or 10%);
- The project budget is defined as the planned value at project completion. This includes re-baselining or scope changes during the project; and
- The project team size is defined as the number of people involved in a project who execute activities that contribute significant to the earned value.

3.1.2 Determining project topology

The method used to calculate the SP-factor was taken from Vanhoucke *(2009)*. In his method the SP-factor measures the closeness of the project activities to a parallel or serial network. The SP-factor can be formulated as follows:

$$SP = \begin{cases} 1 & if\ n = 1 \\ \dfrac{m-1}{n-1} & if\ n > 1 \end{cases}$$

m = maximum number of chains in planning
n = total number of activities.

3.3.3 Determining the S-curve

The relation between the S-curve and the stability of EVM has not been discussed in previous research. As such, a method for measuring the S-curve is not found in literature. In this paragraph a new method is proposed to characterize the planned value S-curve.

At first the standard deviation of the planned value against an imaginary linear value is determined *(see* **Figure 3***)*. The calculated deviations for each time step provide insight into the deviation of the planned value with respect to a 100% linear planning. To quantify the cumulative deviation the root-mean-square-deviation *(RMSD)* is used. This method is frequently used to quantify the deviations between a predicted value of a model and the actually measured or observed value *(Hyndman and Koehler, 2006)*.

The formula used to calculate the RMSD is given below.

$$RMSD = \sqrt{\frac{\sum_{t=1}^{n}\left(x_{t,1} - x_{t,2}\right)^2}{n}}$$

$x_{t,1}$ = values of imaginary linear value at timestep t,
n = values of planned value *(actual S-curve)* at timestep t,
n = number of observations *(timesteps)*.

The calculated RMSD provides project specific information, which makes comparisons to other projects impossible. Indeed, a normalization of the standard deviation is required to make the S-curve measure comparable to other projects. By using the coefficient of variation *(CV)* the normalization can be calculated.

The CV is applied to the RMSD: CV*(RMSD)*. It is defined as the RMSD normalized to the mean of the observed values:

$$CV(RMSD) = \frac{RMSD}{\bar{x}}$$

$\bar{x}$ = average of observed values = average of planned values.

A CV*(RMSD)* value of 0 indicates a project planning with a linear planned value. As the deviations from the linear planning increase, the CV*(RMSD)* increases to a maximum of 1.

3.1.4 CPI and $SPI_{(t)}$ stability

The used definition for stability in this study is similar to its definition in previous research *(Henderson and Zwikael, 2008; Lipke et al, 2009)*. The measure for CPI and $SPI_{(t)}$ stability is defined as the moment in the project lifecycle when:

- $SPI_{(t)} = SPI_{(t)final} \pm (0.1)$;
- $CPI = CPI_{(t)final} \pm (0.1)$.

If, for example, the CPI does not fluctuate more than 0.1 from the projects final CPI as of from time step 4 with a total of 10 time steps, the CPI stability is reached at the 40% completion point of a project. As such the moment of stability is relative and not determined as an absolute value.

3.2 Research approach

The distinction between a quantitative and a qualitative research approach is necessary in order to classify different research methods *(Bry-*

man and Bell, 2011). Indeed, to test the hypotheses a large set of data is preferable. For this reason this research is characterized by its quantitative approach. A qualitative approach leads to less quantitative project data, which makes hypothesis testing by using statistics more difficult, but richer qualitative data is to be collected.

In general, Yin *(1993)* defines three types of case studies: exploratory, explanatory, and descriptive. Exploratory research is sometimes considered preliminary research to further social research. Explanatory case studies seek the causal connections. A descriptive case study is often used to illustrate events and their specific context. This case study can be described as an explanatory case study. A causal connection is sought between the dependent and independent variables are sought using hypotheses.

EVM is applied within many different sectors, different countries and by different project managers thereby offering many potential data sources from which to retrieve the research data. Data can be retrieved from large project databases *(like Cristensen and Heise, 1993)* or be collected individually *(like Henderson and Zwikael, 2008).* In this study the data is collected within the company of Royal HaskoningDHV *(RHDHV).* This data source has been chosen for several reasons:

- Data is more easy accessible since the researcher is employed at RHDHV;
- Using data from RHDHV means this research has added value to the company of RHDHV concerning EVM improvement; and
- The project managers that provided the data used were easily accessible for interviews or additional information that explains the EVM data used.

By using social media a request is posted to contribute to this research by providing project data. The request resulted in three respondents, who again introduced new contacts. In total, there were 9 project used, executed by 5 project managers in this research. Interviews were kept to introduce the research goals, assure confidentiality and assisting in collecting the project data. The collected data is saved in excel databases for further analysis.

3.3 Statistical analysis

The aim of this research is to identify relationships between different *(random)* variables using models or algorithms. The used approach is the simple linear regression analysis, often used because of its versatility, simplicity and easy interpretation *(Rodrígez del Águla and Benítez-Parejob, 2011).*

The correlation coefficient, calculates a value between -1 and 1. The value indicates the degree of correlation between variable X and Y. A positive value indicates a positive linear correlation, while a negative value indicates a negative linear correlation. Taking the square of "r" the coefficient of determination is calculated *(R2).* This value varies between 0 and 1. In general the R2 value > 0.8 indicates a strong correlation; 0.5-0.8 a medium relation; R2 < 0.5 no or a very weak correlation *(Rodrígez del Águla and Benítez-Parejob, 2011).* This method is also used to test if the independent variables influence each other.

4. Results

This chapter presents the results of the data analysis. After describing the data *((paragraph 4.1)*, paragraph 4.2 summarizes the project characteristics. The test results of the hypotheses is summarized in paragraph 4.3.

TABLE 1: *project characteristics.*

Project	Duration* plan	actual	Budget plan	actual	Interval	Team Size	SP factor	Curve factor	Stability* CPI	$SPI_{(t)}$
1	20	28	580.000	573.000	3.57	10	0.15	0.17	32	64
2	16	22	213.000	256.000	4.55	10	0.17	0.15	13	82
3	108	113	520.000	570.000	1.77	5	0.20	0.03	32	22
4	47	55	192.000	286.000	7.27	10	0.33	0.25	57	71
5	33	61	350.000	300.000	1.64	20	0.16	0.22	60	8
6	22	20	180.000	166.000	4.55	10	0.03	0.14	25	40
7	46	46	140.000	144.000	4.35	11	0.27	0.19	20	8
8	26	26	245000	292.000	7.69	13	n/a	0.21	67	79
9	22	26	2080000	2233000	3.85	10	0.04	0.13	15	35

* re-baselining has been taken in consideration.

4.1 Data description

The project data is collected at RHDHV, an engineering, consultancy and project management organization. The projects are executed on behalf of RHDHV clients. In most situations the risk of P&L *(profit and loss)* lies with RHDHV. Therefore sound project management with all its assets is crucial to the profitability of RHDHV and especially focused on costs.

The data is provided in EVM excel sheets used by RHDHV. The excel sheets provide information on the PV, AC and EV and provide CPI and SPI graphs. The SPI is recalculated in this research to the $SPI_{(t)}$. In **Table 1** an overview is given of the project characteristics for each project, from which the variation in data can be seen. **Appendix A** provides an overview of the EVM data for each project.

4.2 Project characteristics (influencing each other)

At first, the independent variables are tested on having significant relationships among each other. It has been shown that there are two possible relationships between:

- S-curve and project duration (R^2: 0.81);
- S-curve and SP-factor (R^2: 0.83);.

In the statistically identified relationship the S-curve increases when project duration increases. In other words, the project complexity increases when the project duration increases.

The second statistical relationship identified is that the SP-factor increases *(relatively more serial project activities)* when the S-curve increases *(higher steepness in s-curve, related to more parallel activities).* This seems to contradict the findings in the literature review which suggest that rework and more parallel organized activities result in increasing the steepness of the s-curve. Hence, the expected relationship is: lower SP-factor *(more parallel organized activities)* leads to a stronger S-curve *(increased project complexity).*

Secondly, the dependent variables CPI and SPI*(t)* are analyzed. The moment of stability is presented in **Figure 4**. In general it can be concluded that in some cases the moment of CPI and SPI*(t)* stability in the research data does happen before the 20% completion point. However, on average the moment of CPI and SPI*(t)* stability is reached at the 38% and 44% completion point of a project respectively. The results of this research show the same pattern that previous research showed, namely that on average the CPI stability is observed at an earlier completion point in a project than the SPI*(t)* stability *(Henderson and Zwikael, 2008; Buyse and Vandenbussche, 2010).*

4.3 Statistical relationships

The data analysis results *(testing of hypotheses as presented in* **Figure 2***)* show two statistical significant relationships. There are additionally three possible relationships, however not statically proven. The results are summarized in **Table 2** and XY scatters between the dependent and independent variables are shown in **Figure 5**. Appendix B provides the test results.

From two out of the twelve hypotheses *(see* **Figure 2** *and* **Table 2***)*, the HO is accepted:

- Hypothesis 3: a significant relation was found between the monitoring interval and CPI stability; and
- Hypothesis 11: a significant relation was found between the S-curve and CPI stability.

Through an analytical approach to interpret the data, three additional relations have been found, namely:

- Hypothesis 2: a relation is visible between the duration and $SPI_{(t)}$ stability;

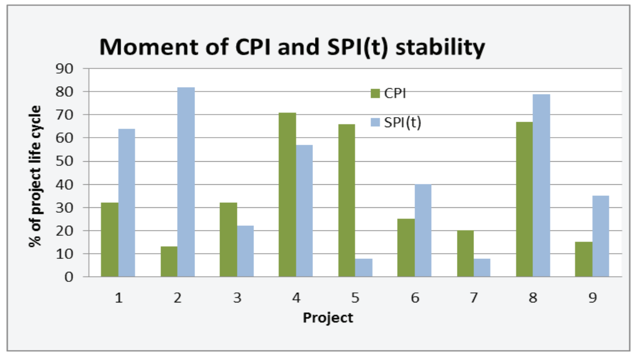

FIGURE 4: *overview of the moment of CPI and SPI(t) stability for each project.*

TABLE 2: *Summary of hypothesis testing results.*

Hypothesis #	Independent	Dependent	Statistical test	Analytical analysis
1	Duration	CPI	Ho rejected	No relation found
2	Duration	$SPI_{(t)}$	Ho rejected	Logical relation visible in XY-scatter.
3	Interval	CPI	Ho accepted*	Logical relation visible in XY-scatter.
4	Interval	$SPI_{(t)}$	Ho rejected	Logical relation visible in XY-scatter.
5	Budget	CPI	Ho rejected	No relation found
6	Budget	$SPI_{(t)}$	Ho rejected	No relation found
7	Team	CPI	Ho rejected	No clear relation found due to low variety (team size) in research data.
8	Team	$SPI_{(t)}$	Ho rejected	No clear relation found due to low variety (team size) in research data.
9	SP-factor	CPI	Ho rejected	No clear relation found due to low variety (SP-factor) in research data.
10	SP-factor	$SPI_{(t)}$	Ho rejected	No clear relation found due to low variety (SP-factor) in research data.
11	S-curve	CPI	Ho accepted**	Logical relation visible in XY-scatter.
12	S-curve	$SPI_{(t)}$	Ho rejected	Logical relation visible in XY-scatter.

* with the exclusion of project #3 and #5 ** with the exclusion of project #3.

- Hypothesis 4: a relation is visible between the monitoring interval and $SPI_{(t)}$ stability; and
- Hypothesis 12: a relation is visible between the S-curve and $SPI_{(t)}$ stability.

No relation was found between the project budget and the stability of CPI and/or $SPI_{(t)}$. The independent variables team size and SP-factor had a small variety of data which makes it impossible to test the hypotheses 7, 8, 9 and 10.

5. Discussion

The results are discussed in relation to what has been found in literature. The dependent and independent variables are discussed in paragraph 5.1. The results on the hypotheses testing are discussed in paragraph 5.2. Paragraph 5.3 discusses validity issues in this research.

5.1 The research variables

In this research, the average moment of CPI stability was found at the 38% completion point in the project and $SPI_{(t)}$ stability at the 44% completion point. The research results do not invalidate the statement made by Fleming and Koppelman *(2010)* that stability can be found as early on in a project as the 20% completion point. Five out of the nine projects used in this research do show stability of the CPI or $SPI_{(t)}$ before the 20% completion point. However, it is remarkable that stability was found at an early completion point for either the CPI or the $SPI_{(t)}$, and not for both. This might be explained by the project manager's focus, which can lie on time or budget?

Some of the independent variables seem to have a relation amongst each other. An increase in the project duration leads to an increase of the S-curve. An increase of the S-curve is, according to Goodman *(2010)*, related to an increase in the project's complexity. Based on these results it can be concluded that an increase in project duration leads to an increase in project complexity. From the literature review no evidence has been found to substantiate this result. An increase in the SP-factor leads to an increase in the S-curve. This result is unexpected and not supported by the literature. It is unexpected because an increase in the SP-factor tells us that the project has been constructed with more serial related activities, which is expected to relate to a lower S-curve *(a more linear baseline)*. Beside the above mentioned relationships, no other relationships have been found between the independent variables.

In this research, no explanation could be found to explain this relationship. However, it has been noted that the SP-factor in this research does not exceed the value of 0.33 and therefore all projects can be considered as having been organized more parallel than serial and therefore the relationship found might not be representative when extrapolated to SP-factors closer to 1 *(linear organized activities)*.

5.2 Hypotheses discussion

5.2.1 Project duration and monitoring interval

In the literature it is suggested that project duration has an effect on the moment CPI and/or $SPI_{(t)}$ stability is reached in the project life cycle *(Lipke, 2005)*. Long duration projects do have longer periods of time in order to find a balance and rhythm that makes stability possible. However, based on the research data no statistically significant relationship could be found between project duration and the moment of CPI and/or $SPI_{(t)}$ stability in a project.

The projects used in this research had a duration varying from 22 weeks to 113 weeks. More variation in project duration is required to test this relationship *(more projects with a duration of several years)*. Although no statistically significant relationship has been found, there seems to be a relation between $SPI_{(t)}$ stability and project duration; when the project duration increases, the moment of $SPI_{(t)}$ stability is found earlier on in the project life cycle.

Custer *(2008)* claims that an increased reporting cycle is needed as the projects get smaller. In this research, a statistically significant relation has been found between the CPI stability and the project monitoring interval. No significant relation was found between the project monitoring interval and the moment of $SPI_{(t)}$ stability, however, a similar trend can be detected when the data results are evaluated analytically. It can be concluded that a minimum monitoring interval of 5% is desirable to have early stability of the CPI and $SPI_{(t)}$. Based on a weekly reporting system a project should have a duration of at least 20 weeks *(100/5)*.

5.2.2 Project budget

The results from this research show no relation between project budget and the moment of CPI and $SPI_{(t)}$ stability. The examined literature suggests that budget is often used in discussing whether or not applying EVM is beneficial in small, limited budget projects *(Cioffi, 2005)*.

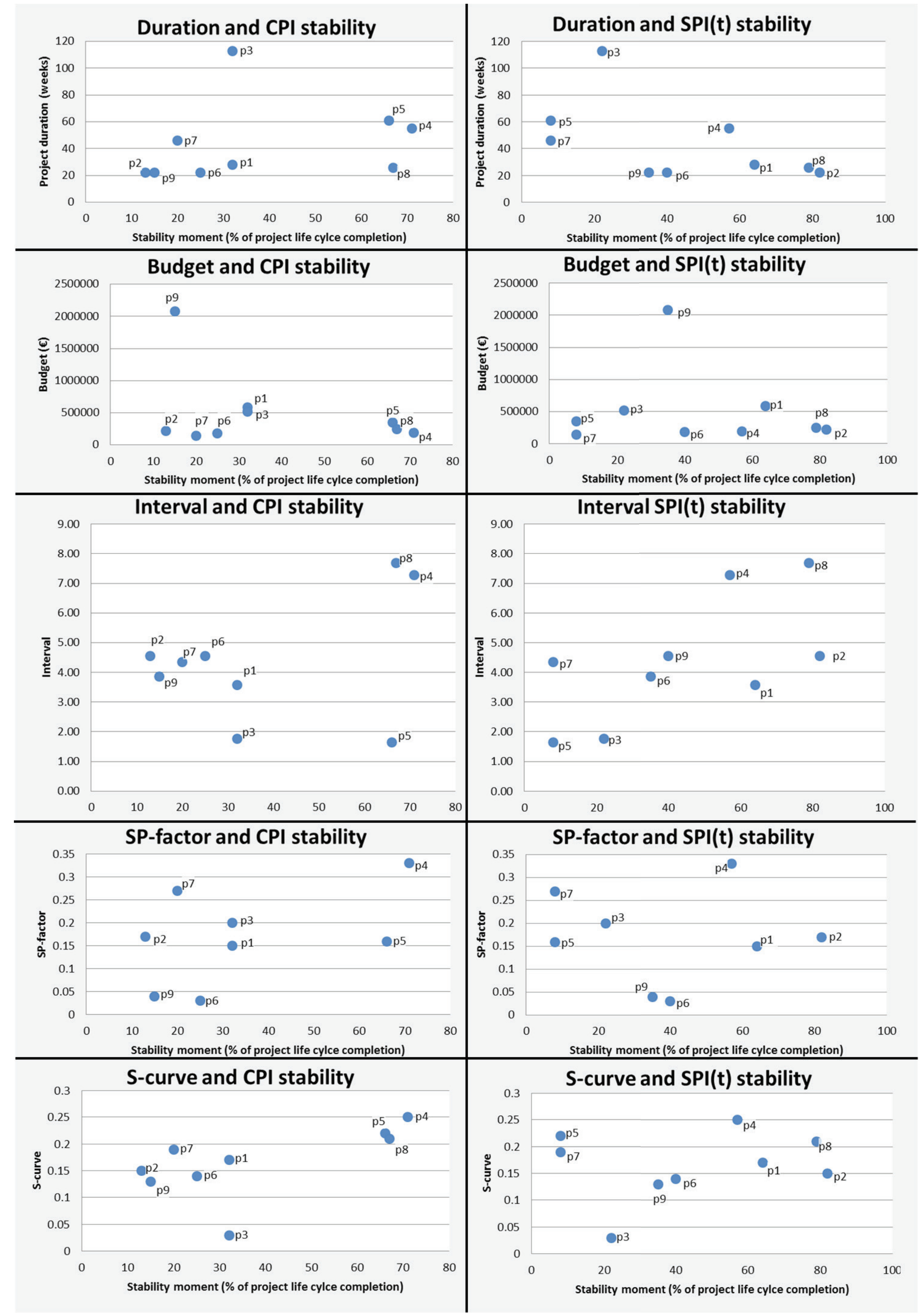

FIGURE 5: *XY scatters of the twelve hypothesis.*

According to Hunter et al *(2002)* the costs of implementing EVM in a project run up to 5% of the total project costs. However, it is likely that in small projects this share of 5% does not hold and will be exceeded. It can be concluded that the project budget does not influence the moment at which CPI and/or $SPI_{(t)}$ stability is reached in the project life cycle. The project's budget is to be considered to determine whether or not it is big enough to support costs related to the implementation of EVM.

5.2.3 Project team size and CPI and $SPI_{(t)}$ stability

Based on the research data, no clear relation between team size and the moment of CPI or $SPI_{(t)}$ stability could be found. This is due to the fact that seven out of the nine studied projects have a team size of 10 or 11 persons. One project had a relative large team size, of 20 persons, and the $SPI_{(t)}$ stability was reached as early on in the project as the 8% completion point, which does not support the idea that large teams have inefficient communication leading to a late moment of CPI or $SPI_{(t)}$ stability. This might be explained by Zwikael and Unger-Aviram *(2010)*, who concluded that the project duration moderates the relationship between team development and project success which might neutralize the possible negative effect of a large team size on efficiency. As such, the project mentioned earlier is the second largest project in this research.

In one of the projects the team is relatively small, only 5 persons, and the duration is relatively long, with 113 weeks, both the moment of CPI *(22%)* and $SPI_{(t)}$*(32%)* stability are seen relatively early on in the project life cycle. This project supports a combined theory that small teams *(Hoegl, 2005)* and long project durations *(Zwikael and Unger-Aviram, 2010)* lead to a relatively early moment in the project life cycle when communication is efficient, resulting in an efficient execution of the project and thus an early moment of CPI and $SPI_{(t)}$ stability. Unfortunately, not enough data with a wide variety in terms of both project team size and project duration was available for this research in order to statistically test this relationship.

5.2.4 SP-factor and CPI and $SPI_{(t)}$ stability

Previously, it has been shown that EVM provides reliable warning signals in a project with a serial structure *(Vanhoucke, 2012)*. Based on these results it is expected that projects with a more serial structure also experience earlier stability of the CPI and $SPI_{(t)}$ due to more efficiency in project control. Based on the research results however it can be concluded that the SP-factor did not influence the moment of CPI and or SPI*(t)* stability which is contradictory to the expectations. The project data used in this research contain a variety ranging from 0.03 to 0.33 in the SP-factor. According to earlier results from Vanhoucke *(2009)*, the shift from SRA to EVM can be found in an SP-factor of approximately 0.4. The variety in the SP-factor might be too small in this research to detect an influence on the moment of CPI and/or SPI*(t)* stability.

5.2.5 S-curve and CPI and $SPI_{(t)}$ stability

The S-curve measure, developed in this research indicates the relative deviation of the project's planned value from an imaginary linear project progress. The increase of the S-value is associated with an increase in terms of the project's *(structural)* complexity which might lead to a later moment in the project life cycle when CPI or SPI*(t)* is achieved. The statistical analysis indicates a positive relationship between the S-curve and the moment of CPI stability. In an analytical analysis the same relation could be found with the moment of SPI*(t)* stability, however from a statistically point of view this is not a significant relationship. Nevertheless, a relation seems to exist between the S-curve and the moment of CPI and SPI*(t)* stability in a project. This result supports the findings from the literature which suggest that the increased structural complexity of a project will affect *(lower)* the efficiency of EVM.

5.3 Research validity

Similar to other studies, this research deals with limitations. The limitations may affect the research outcomes *(internal validity)* but they may also affect to what extent the research outcomes can be extrapolated to other organizations that apply EVM in their projects, also known as external validity *(Bryman and Bell, 2011)*.

5.3.1 Internal validity

In an ideal situation, the research is conducted using a combined approach of qualitative and quantitative research. The scope of this research is limited to a quantitative approach. Because of this approach less attention has been paid to the quantitative aspects such as the experience level of the project manager, the project complexity and an in-depth understanding of how the project was executed in relation to the stability of EVM measures. Therefore, it is possible that project characteristics have been left out the scope that do influence the moment of CPI/SPI*(t)* stability in the project lifecycle.

A statistical analysis is used to find relations between variables. The simple linear regression used serves to predict or explain the relationship between two variables. However, an exact relationship cannot be determined. The statistical analysis is used only as an explanatory or predictive tool *(Marshall, 2007)*. The unexplained relationships between the variables are not further researched as these relationships are beyond the scope of this research. The independent variables may influence each other or moderate the relationship with the dependent variables. To understand these complicated relations a larger dataset is needed. According to of Rodrígez del Águla and Benítez-Parejob *(2011)* a dataset of 60 projects is a minimum when researching 6 independent variables. These amounts of required project data require a much larger and extensive research that was not possible within the context of this research. A larger and broader sample population is therefore desired and always preferable *(Marshall, 2007)*. The need for more project data is also recognized by Batselier and Vanhoucke *(2015)*, who have constructed a database containing project information to be used in future research. This database will be maintained and supplemented with new available project data to support future research. .

5.3.2 External validity

In this research, data from a selection of projects executed at RHDHV has been used. One of the characteristics of this organization is that it performs projects on behalf of other organizations. The financial risk lies with the company of RHDHV. The focus of project managers at RHDHV is as such primarily on budget control and less on planning *(as in project duration)* control. The results must be carefully extrapolated to organizations which execute projects of which they are also the owner, or projects in which time-to-market is the most important drive to complete the project on time *(instead of budget)*.

The positive relationships found are consistent with the findings from the literature. But to extrapolate these results to projects which are very different from the ones used in this research, caution is advised. This is due to the fact that the analysis is based on a relatively small sample of projects carried out by a single organization.

6. Conclusion

The aim of this research is to understand how the stability of CPI and $SPI_{(t)}$ is influenced by project characteristics. Based on literature review the following project characteristics have been identified which might influence the moment of CPI and $SPI_{(t)}$ stability in the project life cycle: project duration and budget, project monitoring interval, the SP-factor and the S-curve of the project's baseline. These characteristics are studied in this research by using empirical data from nine projects. The following can be concluded:

- The use of EVM should not only be based on the project duration alone but it must also be considered in conjunction with the project progress monitoring interval. More intensive project monitoring intervals are related to an earlier moment of CPI stability.
- The project budget should be considered whether or not EVM implementation pays off. There is no relation found between project budget and the moment of CPI/$SPI_{(t)}$ stability.
- Team size might influence the moment of CPI/$SPI_{(t)}$ stability, however is influenced by project duration. Large team sizes together with short project duration might result in achieving stability relatively late in the project life cycle.
- Serial-parallel curve was expected to influence to moment of CPI/$SPI_{(t)}$ stability. EVM seems to be more appropriate in projects with serial organized activities, however was not proven in this research probably due to low variety in the research data of the SP-factor.
- The S-curve, associated with structural project complexity, influences the moment of CPI/$SPI_{(t)}$ stability. The steeper the S-curve line in the middle, the later stability of CPI/$SPI_{(t)}$ is to be expected.

The result of this research might help project managers to understand if EVM is a suiTable project control tool in their project and tests theories of earlier academic research. The proposed measurement of the S-curve in this research assumes a link to project structural complexity. To better understand this assumption a better understanding of project complexity in relation to the S-curve is needed. Moreover, further research on the complexity of projects in relation to the stability of CPI and SPI*(t)* and what the moderating effect of the experience level of the project manager is, is recommended.

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references

Anbari, F.T. *(2003).* Earned Value Project management Method and Extensions. Project management Journal, 34, pp. 12-23.

Elshaer R. *(2013).* Impact of sensitivity information on the prediction of project's duration using earned schedule method. International Journal of Project Management, 31-4, pp: 579-588.

Azimi, R., Lee, S., AbouRizk, S.M., Alvanchi, A. *(2011).* A framework for an automated and integrated project monitoring and control system for steel fabrication projects. Automation in Construction, 20-2011, pp 88–97.

Batselier, J. and Vanhoucke, M. *(2015).* Construction and evaluation framework for real-life project database..International Journal of Project Management 33-2015, pp. 697-710.

Bryman, A., Bell, A. *(2011).* Business Research Methods – 3rd Edition. Oxford University Press Inc. New York, USA.

Buyse, P., Vandenbussche, T. *(2010).* Performance analysis of Earned Value Management in the construction industry. Master thesis faculteit Economie en Bedrijfskunde, Gent University, Belgium.

Christensen, D.S., Payne, K.I. *(1992).* Cost Performance Index Stability – Fact or Friction? Journal of Parametrics, 10:27-40.

Christensen, D.S., Heise, S.R. *(1993).* Cost Performance Index Stability. National Contract Management Association Journal, Volume 25, No. 1-1993.

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

Cioffi, D.F. *(2005).* Designing project management: A scientific notation and improved formalism for earned value calculations. International Journal of Project Management 24-2006, pp. 136-144.

Corovic, R. *(2006).* Why EVM is Not Good for Schedule Performance Analysis *(and how it should be…)*. The Measurable News, Volume 2007, Issue 1, pp. 22-30.

Custer, K. *(2008).* Ten Things You Need to know About Earned Value Management. Custer Consultants Inc.

Czarnigowska, A. *(2003).* Earned value method as a tool for project control. Budownictwo i Architektura 3-2008, pp. 15-32.

Falco, M., Macchiaroli, R. *(1998).* Timing of control activities in project planning. International Journal of Project Management Volume 16, No. 1-1998, pp. 51-58.

Fleming, Q.W., Koppelman J.M. *(2002).* Earned Value Management – Mitigating Risks Associated with Cnstruction Projects. Program Manager, March-April 2002, pp. 90-95.

Fleming, Q.W., Koppelman J.M. *(2004).* Sarbanes-oxley: does compliance require earned value management on projects? Contract Management 2004, 26–8.

Fleming, Q.W., Koppelman, J.M. *(2010).* Earned Value Management – Fourth Edition. Project Management Institute *(PMI)*, Pennsylvania, USA.

Goodman, J. *(2010).* Analyzing S-curves. AACE International Recommended Practices, TCM Framework: 10.1 – Project Performance Assessment.

Henderson, K. *(2005).* The Benefits of Earned Value Management for "Strategic Commercial Imperatives". PMI Global Congress Proceedings-2005, Singapore.

Henderson, K., Zwikael, O. *(2008).* Does Project Performance Exist? A Re-examination of CPI and Evaluation of SPI *(t)* stability. CrossTalk - The Journal of Defense Software Engineering 21-2008, pp. 7-13.

Hoegl, M. *(2005).* Smaller teams - better teamwork: How to keep project teams small. Business Horizons 48-2005, pp. 209-214.

Hyndman, R.J., Koehler, A.B. *(2006).* Another look at measures of forecast accuracy. International Journal of Forecasting, pp. 679–688.

Koppenjan, J., Veeneman, W., Van Der Voort, H., Heuvelhof, E., Leijten, M. *(2010).* Competing management approaches in large engineering projects: The Dutch RandstadRail project. International Journal of Project Management 29-2011, pp. 740 - 750.

Kwak, Y.H., Anbari, F.T. *(2012).* History, Practices, and Future of Earned Value Management in Government: Perspectives From NASA. Project Management Journal, Volume 43, No. 1, pp. 77 - 90.

Lipke, W. *(2003).* Schedule is Different. The Measurable News, Summer 2003.

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

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

Lipke, W. *(2011).* Earned Schedule Application to Small Projects. PM World Today, April 2011, Volume XIII, Issue IV.

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

Payne, K.I. *(1990).* An Investigation of the Stability of the Cost Performance Index. Master thesis, AFIT/GCA/LSY/90S-6, School of Systems and Logistics, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, September 1990.

Popp, M. *(1996).* Probability Distributions of CPI at Complete vs. CPI Today. Internal NAVAIR Report, Unpublished.

Rodríguez del Águla, M.M., Benítez-Parejob, N. *(2011).* Simple linear and multivariate regression models. Allergologia et Immunopathologia, Volume 39, Issue 3, May–June 2011, pp. 159-173.

Tavares, L., Ferreira, J., Coelho, J. *(1999).* The risk of delay of a project in terms of the morphology of its network. European Journal of Operational Research 119, pp. 510 - 537.

Tavares, L., Ferreira, J., Coelho, J. *(2002).* A comparative morphologic analysis of benchmark sets of project networks. International Journal of Project Management 20, pp. 475 - 485.Vandevoorde S, Vanhoucke M. A *(2006).* Comparison of different project duration forecasting methods using earned value metrics. International Journal of Project Management 2006;24:289–302.

Vanhoucke, M., Vandevoorde, S.A. *(2007).* Simulation and evaluation of earned value metrics to forecast project duration. Journal Operational Research Society, 2006 - 24*(4)*, pp. 289 - 302.

Vanhoucke, M., Coelho, J., Debels, D., Maenhout, B., Tavares, L. *(2008).* An evaluation of the adequacy of project network generators with systematically sampled networks. European Journal of Operational Research 187, pp. 511 - 524.

Vanhoucke, M. *(2009).* Measuring Time – Improving Project Performance Using Earned Value Management. International Series in Operations Research & management Science, Volume 136, Springer.

Vanhoucke, M. *(2010).* Using activity sensitivity and network topology information to monitor project time performance. Omega 38-2010, pp. 359 - 370.

Vanhoucke, M. *(2011).* On the Dynamic use of project performance and schedule risk information during project tracking. Omega 39-2011, pp. 416-426

Vanhoucke, M., Shtub, A. *(2011).* Adding Value to Earned Value Analysis. PM World Today, January 2011, Volume XIII – Issue I.

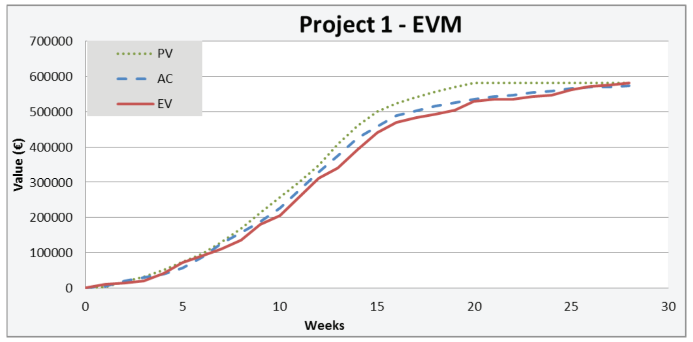
Vanhoucke, M. *(2012).* Measuring the efficiency of project control using fictitious and empirical project data. International Journal of Project Management 30-2012, pp. 252 - 263.

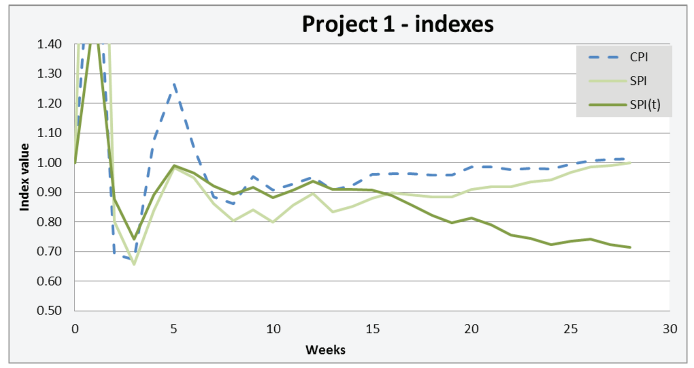
Yin, R. *(1993).* Applications of case study research. Newbury Park, CA, Sage Publishing.

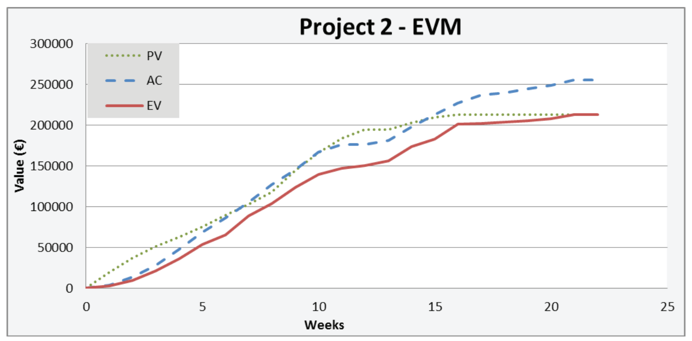
Zwikael, O., Globerson, S., Raz, T. *(2000).* Evaluation of Models for Forecasting the Final Cost of a Project. Project Management Journal, Volume 31, No. 1, pp. 53-57.

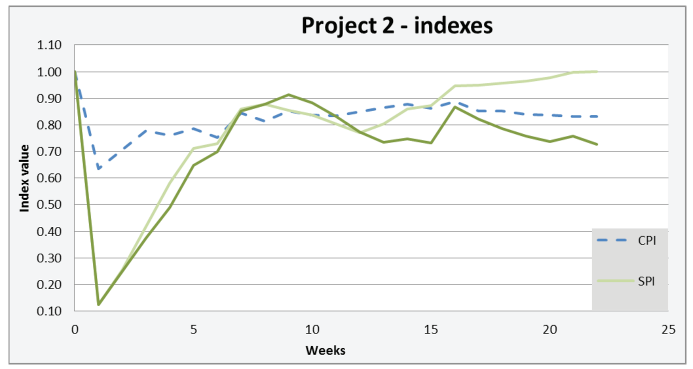
Zwikael, O., Unger-Aviram, E. *(2010).* HRM in project groups: The effect of project duration on team development effectiveness. International Journal of Project Management 28-2010, pp. 413 - 421.

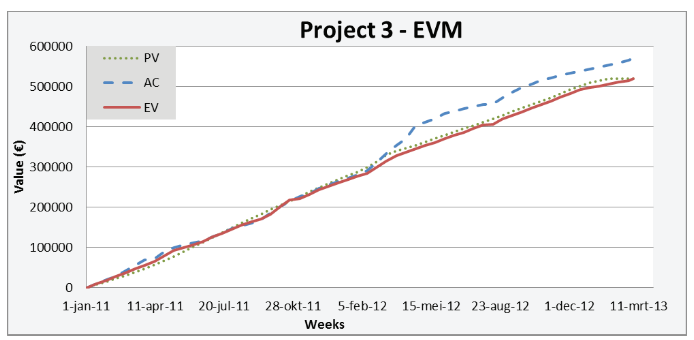
APPENDIX A
EVM DATA OF PROJECTS

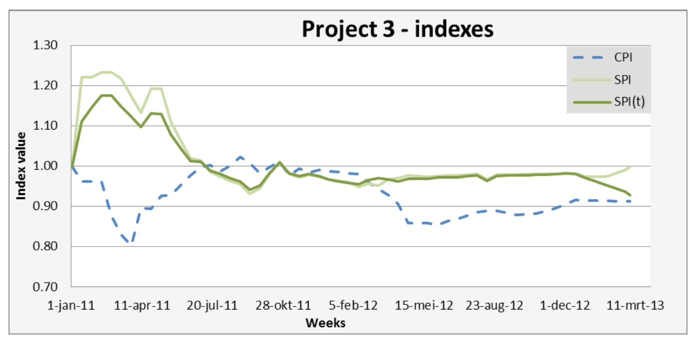


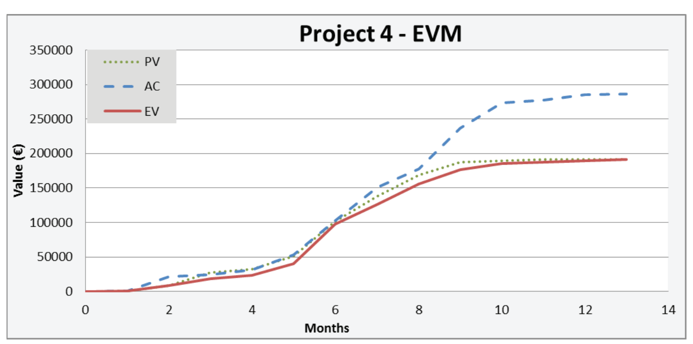


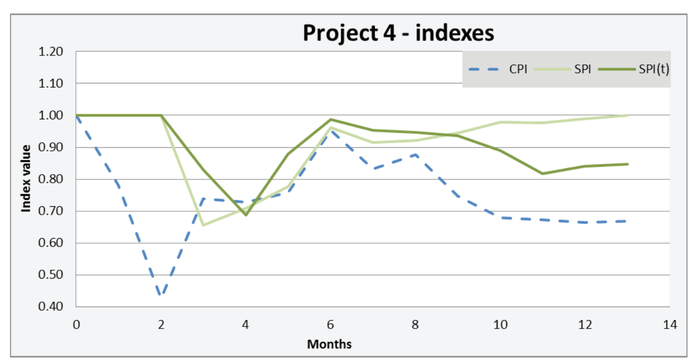


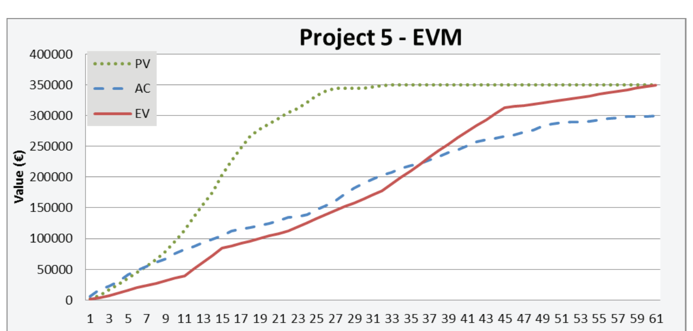


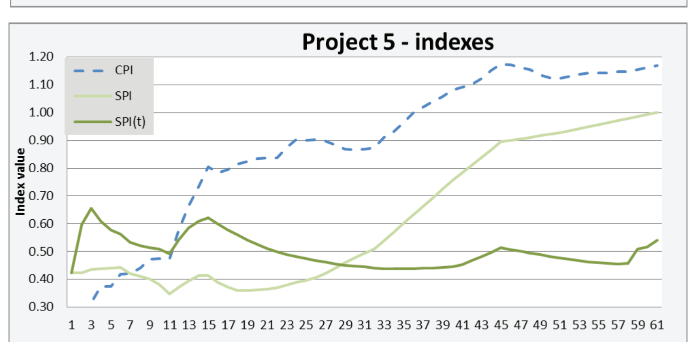


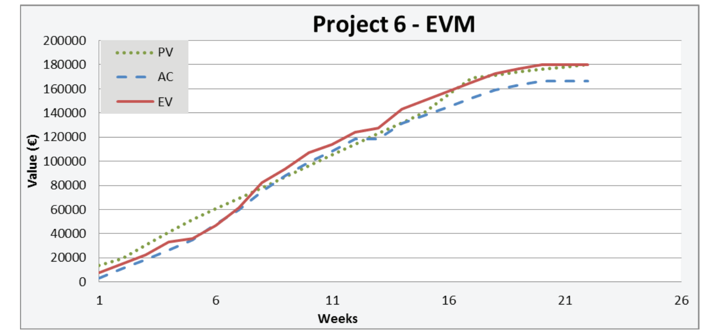


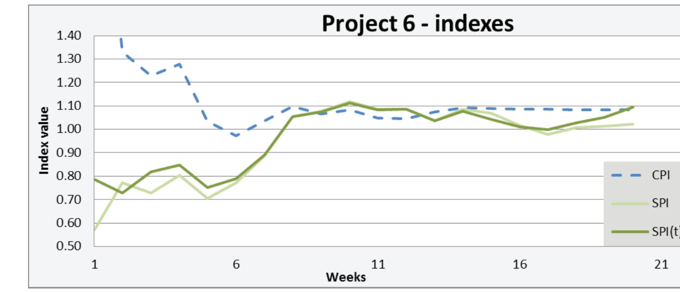


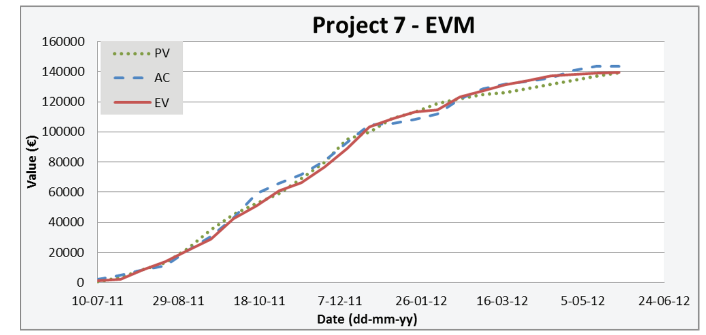


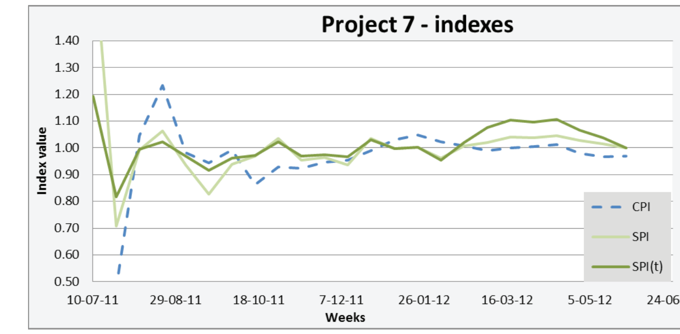


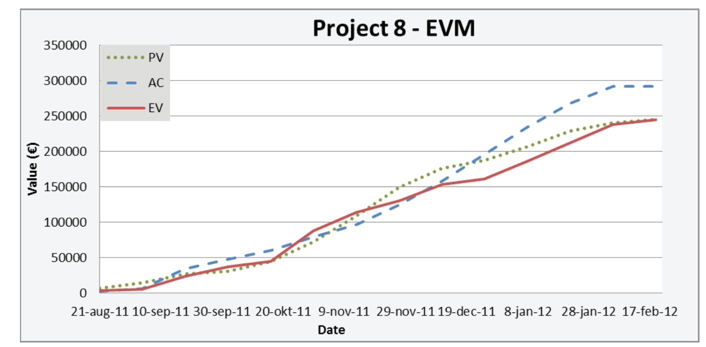


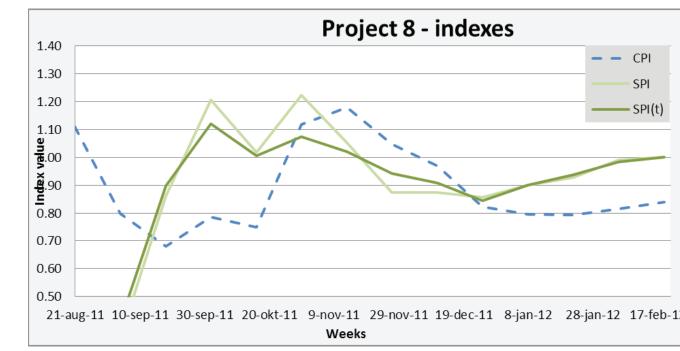


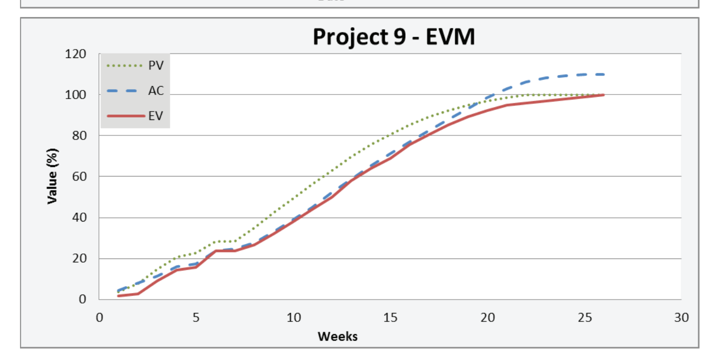


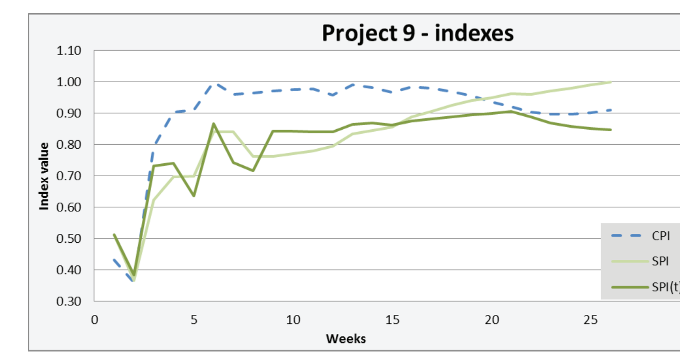












APPENDIX B
STATISTICAL TEST RESULTS

Hypothesis	Independent variable	Dependent variable	R-square
1	Duration	CPI	0.53
2	Duration	$SPI_{(t)}$	0.364
3	Monitoring interval	CPI	0.826*
4	Monitoring interval	$SPI_{(t)}$	0.346
5	Budget	CPI	0.127
6	Budget	$SPI_{(t)}$	0.44
7	Team size	CPI	0.158
8	Team size	$SPI_{(t)}$	0.101
9	SP-factor	CPI	0.245
10	SP-factor	$SPI_{(t)}$	0.105
11	S-curve	CPI	0.787**
12	S-curve	$SPI_{(t)}$	0.008

TABLE A.1: *statistical test results (simple linear regression, R-squared)*

* exclusion of project #3 and #5
** exclusion of project #3.