STABILITY OF EARNED VALUE MANAGEMENT

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

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 others 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 value of EVM.

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):

- SPI: Schedule Performance Index
- CV: Cost Variance
- CPI: Cost Performance Index
- PV: Project Baseline
- EV: Earned Value
- SV: Schedule Variance
- CPI = CV/PV
- SPI = SV/PV
- CPI = EV/AC
- SPI = EV/PV

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 of the project being over its deadline or not (Corovic, 2006). To overcome this problem, Lipke (2006) developed the Earned Schedule (ES) with the indicators SV, ES, and SPI. The ES method uses time-based metrics instead of monetary metrics for project duration aspects.

In Figure 1.A, the concept of ES is visualized. The ES measures the 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 (Kirk and Anbari, 2003). Therefore, it is important to project managers that they can rely on EVM to determine what extra effort is needed to improve the efficiency of the remaining contractual effort (Christensen and Payne, 1992). Henderson and Zwikael (2000) 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 (Kirk and Anbari, 2003), 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 (USDods) (Lipke et al.,
2. Stability in EVM

In this chapter an overview is given of previ- ous research with a direct or indirect link to ex- plaining the moment of CPI/SPi/s stability in the project life cycle. Firstly the stability is described in paragraph 2.1. Paragraph 2.2 summarizes previous research on CPI/SPi/s stability whereas paragraph 2.3 deals with projects in rela- tion to CPI/SPi/s 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 re- search to define CPI and SPi/s stability. Both methods define boundaries for CPI and SPi/s that are not allowed to exceed in order to be stable. Both methods use the final CPI and SPi/s value to determine the upper and lower bound. Where- as, 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 a constant set of values (0.1) from which lower and upper bound are derived (Henderson and Zwikael, 2008; Lipke et al., 2009).

Boundaries with 10%: 
\[
\text{SPI} = \text{SPI}_{\text{final}} \pm (\text{SPI}_{\text{final}} \times 0.1) 
\]

Boundaries with value 0.1: 
\[
\text{SPI} = \text{SPI}_{\text{final}} \pm (0.1) 
\]

Literature is inconclusive on which method is best to use or does it contain pros or cons for each method. Both methods seem to be accept- able to be used.

2.2 Review on CPI and SPi/s stability

2.2.1 Stability of CPI

Fleming and Koppelman (2010) suggest that CPI and SPi/s 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 conduct- ed 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. Therefore research on the stability of the CPI was not considered useful (Lipke et al., 2009).

Henderson and Zwikael (2008) were the first to study the SPi/s stability. They used 37 projects in their analysis. The results show a wide variety in the moment when the SPi/s is stable. The sta- bility 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/s is reached in the 80% to 100% completion stage of the project life cycle.

Research conducted by Buyse and Vandem- bussche (2010) included five projects in the construction industry. The SPi and SPi/s stability was reached at the 90% completion stage of all projects. Some reasons they found for the late stability of the SPi/s were:

- Slow start-up of the project due to architectur- al difficulties;
- Additional work and work not caused by others near the end of the project.

The research has shown contradicting results on the moment in which CPI or SPi/s stability is found. Although it does show that sta- bility 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/s. 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/s in an early phase of a project is also dependent on how well the management control systems are func- tioning and on the ability of the project manager to correct deviations and to stick to the plan. These factors vary widely across industries, compa- nies, and even teams and individuals.

2.2.2 Stability of the SPi/s

Research on the stability of the SPi/s has not been widely conducted. The SPi/s 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).

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2.3 Project Characteristics

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 Koppel- man (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 assump- tion is applicable to large projects only.

Buyse and Vandembussche (2010) were able to show a relation between the project life cycle and the stability moment of the CPI. A decrease in project duration leads to a later moment in a project’s life cycle where the CPI is stable. These results support Lipke’s statistical calculations (Lipke, 2005) that the moment of CPI or SPi/s stability is related to the project’s duration. This chapter further 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 \(CPI_{\text{CPI/s}} < 0.5\) to be true. 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 \(CPI_{\text{CPI/s}} < 0.5\) has its limitations with respect to project dura-
SCHEDULING // STABILITY OF EARNED VALUE MANAGEMENT DO PROJECT CHARACTERISTICS INFLUENCE THE STABILITY MOMENT ...

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 increasing reporting cycle is required when projects get smaller.

Large projects with long fluctuations of the CPI and SPI, 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 and SPI. 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 the role of budget in EVM and hypothesized that EVM is not applicable to EVM to small projects:

- Project managers believe EVM is not suited for small projects
- 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 Room 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 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 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 mean that in long duration projects the control becomes more efficient thereby creating a stable CPI or SPI, 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 I2 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 value 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 Vandervoort (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): “a simulation technique to reveal the critical components of a project that likely have the biggest impact on the project object,” 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 and 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 are 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 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 Aalstea (2013), Flemming and Kopppejan, 2002, Goodman (2010), Pajerés and López-Paredes (2014), Czarniowska (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. 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 stability since the project duration forecasting methods rely heavily on the SPI.

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 steepness of the S-curve. Kopppejan 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 actions which are subject to change. Dynamic complexity results in unpredictability, uncertainty and emergent behavior. In managing projects the 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 by analyzing 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 (Kopppejan 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 managers 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 extra work. In “letters to the editor” (Harvard Business Review) a complex project is regarded as a project which has an an aspect of new technical components which will not be part of the old project (odds to the project object). Technically complex projects will consist of a straight line of discrete activities with clear beginnings and endings. Indeed, technical projects require an iterative approach. 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 (Kopppejan et al, 2010), because unreliable results can be expected...
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 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) in projects since the development of EVM. The research available and reviewed in this paper has shown that SPI 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 (2010). Although little research was found concerning the relation between CPI and SPI 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;
- 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 stability (dependent variables).

![Figure 2: Conceptual research design](image)

In total, there are 12 hypotheses to be distinguished (6 x 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 baseline is defined as the planned value or scope completion. This includes re-baselining or scope changes during the project;
- 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:

\[
SP = \left[\frac{n}{m}\right]^{t} < 1
\]

where:
- \(SP\) = SP-factor (t);
- \(n\) = total number of activities;
- \(m\) = maximum number of chains in planning;
- \(t\) = timestep (t).

The method is frequently used to quantify the structural complexity (the project structure) or scope changes during the project. This method is used to measure the S-curve.”

3.1.3 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 S-curve.

At first the standard deviation of the planned value against an imaginary linear value is determined (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.

\[
RMSD = \sqrt{\sum_{t=1}^{n}(x_{t} - \bar{x})}\]

where:
- \(x_{t}\) = values of imaginary linear value at timestep \(t\);
- \(\bar{x}\) = 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:

\[
CV(RMSD) = \frac{RMSD}{\bar{x}}
\]

where:
- \(\bar{x}\) = 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 stability

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

- \(CPI_{final} = CPI_{final} \pm 0.1\),
- \(SP = SP_{final} \pm 0.1\).

If, for example, the CPI does not fluctuate more than 0.1 from the projects final CPI as of from step 4 with a total of 10 time steps, the CPI stability is reached at the 4th step 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 hypothesis 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 conclusive. Exploratory research is sometimes considered preliminary research to further social research. Exploratory 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 easily 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 confidence 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 relations 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 (Rodríguez del Águla and Benítez-Parejo, 2011).

The correlation coefficient, calculates a value between -1 and 1. The value indicates the degree of correlation between variables 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 (Rodríguez del Águla and Benítez-Parejo, 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.

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 possibilities between:
1. S-curve and project duration (R2: 0.8)
2. S-curve and SP-factor (R2: 0.8)

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 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 shown: 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 is related to 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, 2000; Byun and Vandenbussche, 2010).

4.3 Statistical relationships
The data analysis results (testing of hypotheses as presented in Figure 2 and Table 2) show two statistical significant relationships. There are additionally three possible relationships, however not statically proven. The results are summarized in Table 3 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 5: a significant relation was found between the monitoring interval and CPI stability.
Hypothesis 11: a significant relation was found between the S-curve and CPI stability.

Through an analytical approach to interpret the data, three additional relationships have been found, namely:
Hypothesis 2: a relation is visible between the duration and SPI(t) stability.

TABLE 2: Summary of hypothesis testing results.

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Statistical test</th>
<th>Analytical analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration</td>
<td>t-test</td>
<td>No relation found</td>
</tr>
<tr>
<td>CPI</td>
<td>t-test</td>
<td>No relation found</td>
</tr>
<tr>
<td>Interval</td>
<td>t-test</td>
<td>No relation found</td>
</tr>
<tr>
<td>Project</td>
<td>ANOVA</td>
<td>No relation found</td>
</tr>
<tr>
<td>CPI</td>
<td>ANOVA</td>
<td>No relation found</td>
</tr>
<tr>
<td>SPI(t)</td>
<td>ANOVA</td>
<td>No relation found</td>
</tr>
</tbody>
</table>

**Hypothesis 3: the moment of stability CPI and SPI(t) is in the same year.**

**Hypothesis 4: a relation is visible between the duration and SPI(t) stability.**

**Hypothesis 5: a significant relation was found between the monitoring interval and CPI stability.**

**Hypothesis 11: a significant relation was found between the S-curve and CPI stability.**
Hypothesis 4: a relation is visible between the monitoring interval and SPI(t) stability; and
Hypothesis 13: 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 dependent 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 parallel 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.

Caster (2009) 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 (Coffe, 2005).
According to Hunter et al. (2002) the costs of implementing EVM in a project run up to 3% 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 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 report 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 correlation between team size and the moment of CPI or SPI(t) stability could be found. This is due to the fact that several 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, 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 have relative large team size, of 20 persons, and SPI(t) stability is seen in projects where the project 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 have relative large team size, of 20 persons, and SPI(t) stability is seen relatively early on in the project life cycle.

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-value and the moment of CPI(t) stability, however from a statistically point of view this is not a significant relationship. Nevertheless, a relation seems to exist between the S-value and the moment of CPI stability, however from a statistically point of view this is not a significant relationship. Nevertheless, a relation seems to exist between the S-value and the moment of CPI stability, however from a statistically point of view this is not a significant relationship. Nevertheless, a relation seems to exist between the S-value and the moment of CPI stability, however from a statistically point of view this is not a significant relationship.

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 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 methods. The scope of this research is limited to a quantitative approach. Because of this approach less attention has been paid to the qualitative aspects and 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 relationships with the dependent variables. To understand these complicated relations a larger dataset is needed. According to of Rodriguez del Agüla and Benitez-Parejoh (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 driver 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
- The S-curve of the project

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 the 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 how 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 is a possible link to project structural complexity.

To better understand this assumption a better understanding on project characteristics 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.


Dynamic Project Planning - Designing-for-Business”, and “Business Statistics”. He is an advisor for several PhD projects, has published more than 50 papers in international journals and is the author of four project management books written by Springer. He is a regular speaker on international conferences as an invited speaker or chairman and a member of numerous project articles submitted for publication in international academic journals. Mario vanhoucke is a founding member and Director of the EVA Europe Association (www.evaeurope.eu) and partner of the company vanhoucke & cie (www.evaeurope.eu). His project management research has received multiple awards including the 2008 International Project Management Association (IPMA) Research Award for his research project “Measuring Time - A Project Performance Simulation Study” which was awarded at the IPMA world congress held in Rome. He also received the “Notable Contributions to Management Accounting Literature Award” awarded by the American Accounting Association at their state conference in Denver, Colorado.

The purpose of the project is to improve project performance by providing tools for project management and control. This paper presents a methodology for measuring performance in construction projects using earned value analysis (EVA) techniques. The methodology was applied to a construction project in the Netherlands and showed that it is possible to improve project performance by using EVA techniques. This is important for project managers as it can help them to identify areas where the project is underperforming and take corrective actions to improve performance.

The paper concludes with a discussion of the implications of the findings for future research in project management and control. It is suggested that further research is needed to develop more advanced EVA techniques that can be applied to more complex construction projects.

References


Dynamic Project Planning - Designing-for-Business”, and “Business Statistics”. He is an advisor for several PhD projects, has published more than 50 papers in international journals and is the author of four project management books written by Springer. He is a regular speaker on international conferences as an invited speaker or chairman and a member of numerous project articles submitted for publication in international academic journals. Mario vanhoucke is a founding member and Director of the EVA Europe Association (www.evaeurope.eu) and partner of the company vanhoucke & cie (www.evaeurope.eu). His project management research has received multiple awards including the 2008 International Project Management Association (IPMA) Research Award for his research project “Measuring Time - A Project Performance Simulation Study” which was awarded at the IPMA world congress held in Rome. He also received the “Notable Contributions to Management Accounting Literature Award” awarded by the American Accounting Association at their state conference in Denver, Colorado.

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The paper concludes with a discussion of the implications of the findings for future research in project management and control. It is suggested that further research is needed to develop more advanced EVA techniques that can be applied to more complex construction projects.
# APPENDIX A

**EVM DATA OF PROJECTS**

<table>
<thead>
<tr>
<th>Project</th>
<th>EVM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project 1</td>
<td>EVM</td>
</tr>
<tr>
<td>Project 2</td>
<td>EVM</td>
</tr>
<tr>
<td>Project 3</td>
<td>EVM</td>
</tr>
<tr>
<td>Project 4</td>
<td>EVM</td>
</tr>
<tr>
<td>Project 5</td>
<td>EVM</td>
</tr>
</tbody>
</table>

# APPENDIX B

**STATISTICAL TEST RESULTS**

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Independent variable</th>
<th>Dependent variable</th>
<th>R-square</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Duration</td>
<td>CPI</td>
<td>0.53</td>
</tr>
<tr>
<td>2</td>
<td>Duration</td>
<td>SPI(t)</td>
<td>0.127</td>
</tr>
<tr>
<td>3</td>
<td>Monitoring interval</td>
<td>CPI</td>
<td>0.008**</td>
</tr>
<tr>
<td>4</td>
<td>Monitoring interval</td>
<td>SPI(t)</td>
<td>0.010</td>
</tr>
<tr>
<td>5</td>
<td>Budget</td>
<td>CPI</td>
<td>0.245</td>
</tr>
<tr>
<td>6</td>
<td>Budget</td>
<td>SPI(t)</td>
<td>0.058**</td>
</tr>
</tbody>
</table>

* exclusion of project #9 and #10
** exclusion of project #5

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