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UNIVERSIDADE DO PORTO

DEVELOPMENT OF A COLLABORATIVE TOOL FOR WORK PLANNING USING EVM (EARNED VALUE MANAGEMENT) METHOD

ANA ALEXANDRA RAMALHO MATEUS

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Supervisor: Professor João Pedro da Silva Poças Martins

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DEPARTAMENTO DE ENGENHARIA CIVIL

Tel. +351-22-508 1901

Fax +351-22-508 1446

✉ miec@fe.up.pt

Editado por

FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO

Rua Dr. Roberto Frias

4200-465 PORTO

Portugal

Tel. +351-22-508 1400

Fax +351-22-508 1440

✉ feup@fe.up.pt

http://www.fe.up.pt

To my grandfather Manuel Joaquim Pereira Ramalho

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ABSTRACT

Today's unpredictable economic environment, propel the late change on how the construction industry see the added value to their companies by combining IT and management processes.

Collaborative tools are posing to be a satisfactory response in low levels of productivity oversee throw-out the industry. Collaborative construction project management IT tools are still in development but have already proven to be suitable answer to control of project cost and time overruns.

While the EVM (Earned Value Management) technique has been used in other industries such as software and product development to a wide extent, its applicability within the construction industry is still overlooked as a common practice in project management.

The aims of this research were to design and develop a framework for a collaborative tool to give feedback on project performance using the EVM (Earned Value Management) method.

With this study, the framework for performance reporting developed at the company *Águas do Porto* (AdP) has two different formats, Up-to-Date and Monthly. A satisfactory response to the content and use of the developed reports was analyzed.

KEYWORDS: EVM, Collaborative Tools, Project Management, System Development, Performance Reporting.

RESUMO

A imprevisibilidade característica do ambiente económico atual leva a que as empresas do sector da construção vejam o valor acrescentado que advém da combinação das Tecnologias da Informação (IT) com processos de gestão.

As ferramentas colaborativas tornam-se imperativas na resposta aos baixos níveis de produtividade que caracterizam o sector. A integração das ferramentas colaborativas com as IT, aplicadas à gestão de projeto no sector da construção ainda se encontra numa fase de desenvolvimento, mas já deram provas de que podem ser aplicadas como resposta para controlo de derrapagem, tanto de custos de projeto como de tempo.

Enquanto o recurso à técnica EVM (*Earn Value Management*) tem sido largamente utilizado noutros sectores industriais, tais como o desenvolvimento de *software* e de produto, a sua aplicabilidade na indústria da construção é ainda subvalorizada como prática corrente na gestão de projeto.

O objetivo deste trabalho passou pelo desenvolvimento e concepção de uma *framework* para uma ferramenta colaborativa de forma a conhecer-se a performance de um dado projeto utilizando o método EVM.

Com este estudo, a *framework* para a obtenção de relatórios de desempenho, desenvolvida na empresa *Águas do Porto* (AdP) assume dois formatos diferentes, dividindo-se no formato em tempo real, e relatórios em formato mensal. Foi analisada uma resposta satisfatória do conteúdo e utilização dos relatórios resultantes.

PALAVRAS-CHAVE: EVM, Ferramentas Colaborativas, Gestão de Projeto, Desenvolvimento de Sistemas, Relatórios de Performance.

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LIST OF ABBREVIATIONS

IT – Information Technology

EVM - Earned Value Management

CPM – Critical path Method

PV - Planned Value

BCWS – Budgeted Costs for Works Scheduled

AC - Actual Cost

ACWP – Actual Cost for Works Performed

EV - Earned Value

BCWP – Budgeted Costs for Work Performed

BAC - Budget at Completion

DAC - Duration at Completion

DoD - United States Department of Defense

C/SCSC – Cost and Schedule Control Systems Concepts

ANSI/EIA - American National Standards Institute

WBS - Work Breakdown Structure

PMB - Performance Measurement Baseline

PMBOK GUIDE - Guide to the Project Management Body of Knowledge

CAP - Control Account Plan

PERT - Program Evaluation and Review Technique

SV - Schedule Variance

SV% - Schedule Variance Percentage

SPI - Schedule Performance Index

TEAC - Time Estimate at Completion

TVAC - Time Variance at Completion

CPI - Cost Performance Index

CV – Cost Variance

CV% - Cost Variance Percentage

EAC - Estimate at Completion

VAC - Variance at Completion

CR – Critical Ratio

ETC – Estimate at Complete

TCPI – To be Complete Performance Index

PVRate – Planned Accomplished Rate

A/E/C – Architecture/Engineering/Construction

KDSS-CPM - Knowledge Based Decision Support System for Construction Project Management

AdP – Águas do Porto
DN – Nominal Diameter

PN – Nomimal Pressure

CAD - Computer-Aided Design

BOQ – Bill of Quantities

VBA – Visual basic for applications

PC142/2011 – Project code name for the implementation case study model

1

INTRODUCTION

1.1. BACKGROUND TO THE PROBLEM

Delays in construction projects have negative effects for all parties involved. Various studies on causes for such delays have been conducted and it has been shown that approximately one-third of all construction projects are exceeding both time and budget limits. (YEO and NING, 2002) Time and budget deliveries are key competitive factors for any construction organization, setbacks in such factors have negative effects both for owners and contractors. While owners might suffer loss of revenue or damages to the company’s image, contractors might face higher overhead costs, longer work periods and also decreased chances in future bids. Thus, having a tool capable of foreseen such delays and overruns is in the interest of every party involved (DAVE and KOSKELA, 2009).

Several studies indicate planning and monitor of a project as cause for delays and overruns. Current practices in project planning consider the integration of all project phases into a single schedule, application of CPM, resource-loading of project schedule, detailed review of the schedule, resource allocation and cost estimates per activity. Such techniques force the project team to break down the project into smaller pieces of work and defining relations between activities, helping reduce project delays. The resulting baseline of the work scope could be used for project controlling during execution, and this is where the EVM (Earned Value Management) method is brought into play. Formatting a basis for corrective action to take place, if necessary, to prevent foray of cost, time and scope is also a necessary step towards effective project management in construction (FLEMING and KOPPELMAN, 1999a).

Construction’s multidisciplinary aspect as lead, now more than ever before, to a high level of integration required from the several participants involved in the process. Pressures to reduce lead times, cost overruns, using fewer resources have increased. In addition, such high level of integration leads to pressures to improve communication platforms among colleagues and to establish consistency in tools and procedures used (GARNER and MANN, 2003, NITITHAMYONG and SKIBNIEWSKI, 2004). In order to tackle the above issues, organizations try to incorporate some form of computer-supported collaborative tool into routinely practices of their professionals. Even though such collaborative tools are widely incorporated into the professionals work and have been viewed as a strategic solution to increase competitiveness, reports still challenge the industry to reduce construction costs by up to 30% (MARSH and FLANAGAN, 2000). Aside from increasing values of IT spending and usage in most of the organizations, the sector still is challenged when it comes to information technology acceptance, even being labeled as a low-tech industry when compared with IT related process innovation levels on other industries (MARTINS, 2009).

1.2. Research Goals and Methodology

To design and develop a framework for a collaborative tool to manage project performance using the EVM (Earned Value Management) method applicable in a work environment was the main goal of this research. The methodology used was action and participatory research on the case study environment.

1.3. Dissertation Contents

The text is subdivided in seven chapters. Literature review on the subjects EVM and Collaborative tools was outlined in the second and third chapters accordingly. The case study organization characterization is detailed in the fourth chapter. The developed model is represented in the fifth chapter. Implementation and model’s evaluation was analyzed in the sixth chapter. Closing notes and future research was overviewed in the seventh chapter.

2
EARNED VALUE MANAGEMENT

2.1. THE EVM METHOD ON MONITORING PROJECT EXECUTION

Feedback is crucial for maintaining projects within their schedule and cost baseline. Cost control tools help project managers get a handle on project plan execution with budget updates and forecasting of final results. (CHOU [et al.], 2010) With its bottom-up approach, Earned Value allows data collection to take place during the entire duration of the project's lifecycle, while requiring in depth information on three main project inputs: scope, time, cost, are required from its users full project's scope definition and detailed time-cost planning (MARSHALL, 2007). It calculates cost and schedule variances, performance indices, and it also forecasts project cost and schedule at completion. Evaluating work packages performance can be measured in euros, hours, worker days, or any other similar unit. Underrated and underutilized, in the construction industry EVM might play a crucial role in tackling many problems associated with the sector's work practices (FLEMING and KOPPELMAN, 2002).

The current chapter will start by giving the reader a comprehensive read on the project management knowledge areas where EVM steps in, and how it is able to give its performance indicators. The last subchapter will be focused on reviewing whether it might be useful in a construction organization specifically the organizations focused on horizontal repetitive projects (exp. water supply systems), as the company studied throughout this research.

2.2. KEY COMPONENTS

EVM employs three base parameters to evaluate work accomplishment. These three dimensions enable EVM to incorporate project's scope, schedule and cost on a unified basis for the purpose of monitoring and forecasting project performance (ANBARI, 2003, PROJECT MANAGEMENT, 2004). The three metrics are, as illustrated by figure 1:

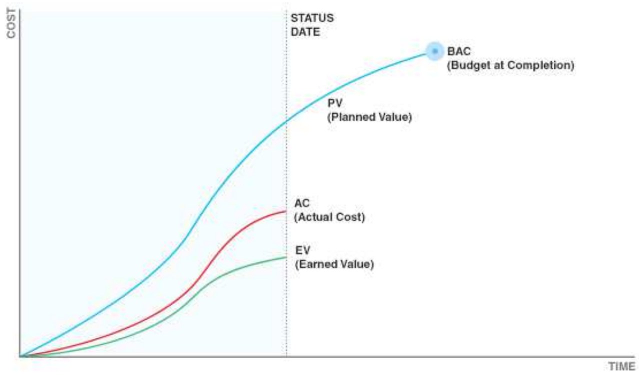

Figure 1 - EVM Graphical Representation

- Planned Value (PV) - Approved time-phase budget baseline to accomplish the entire project. It can be viewed as the value to be earned (or spend) as a function of project work accomplishments up to a given point in time. It can be also named Budgeted cost of Work Scheduled (BCWS); the PV can be achieved through cost estimation, see section 2.4.3.1;
- Actual Cost (AC) - Cumulative cost spends, to actually achieve a work activity within a project. It can be also named Actual Cost of Work Performed (ACWP); example of how AC can be achieved in the owner's perspective are the monthly payments issued to the contractor;
- Earned Value (EV) - Represents the amount budgeted for performing the work that was produced up to a given point in time. It can be obtained by multiplying the activity's total budget by its completed portion. It can be also named Budgeted Cost of Work Performed (BCWP).

Other primary elements are:

- Budget at Completion (BAC) - The highest value of the cumulative Planned Value curve, and the total budget baseline assigned to complete the entire project's work;
- Duration at Completion (DAC) – The approved time frame for project completion.

Another element that combines both BAC and DAC, called the planned value rate, PV rate, and can be defined by the average PV per time period, and given by the formula 1 (ANBARI, 2003):

$$PVRate = \frac{BAC}{DAC} \qquad (1)$$

2.3. How EVM Works

Originally, dating back from the late 1800s, the concept came from industrial engineers who, on the factory floor, have used the three-dimensional approach listed above to assess cost performance, in its most basic form. Industrial engineers compared their *earned standards*, the physical factory output, against the *actual costs* incurred. Then *actual costs* were compared with *planned standards*, the original physical work planned to be accomplished to estimate the schedule results and cost variances (FLEMING and KOPPELMAN, 1998).

A formal concept of Earned Value was introduced by the United States Department of Defense (DoD) around 1967. Completed with a selection of 35 criteria of cost schedule control, C/SCSC was used in large acquisition programs to retain "risk" of cost growth (FLEMING and KOPPELMAN, 1999a). The use of earned value by other governments has been largely reported over the last 30 years. However the set of strict criteria has intimidated the private industry for years, inhibiting a broader implementation of the concept. To encourage wider use, the C/SCSC criteria were abandoned and a more flexible use of the concept was formally issued as the Earned Value Management System in December 1996. Project Management Institute's A Guide to the Project Management Body of Knowledge (PMBOK GUIDE) provided the simplified terminology and formulas. EVM was finally codified by the American National Standards Institute (ANSI/EIA) as Standard #748, in July 1998 (ANBARI, 2003, MARSHALL, 2007).

Over the last two decades, rapid change of this presumption has been documented. Both global competition and technological developments propel this change. Popular project management software packages also play an essential role when it comes to persuade established mindsets. Companies want

to give a reliable response to their project control growing demands, changing EVM's image into a widely spread system (ABBA, 1997).

EVM is an inclusive methodology used to monitor efforts within a project. The methodology comprises many fields of project management, including project organization, planning, scheduling and budgeting, accounting, analysis, reporting, and change control (FLEMING and KOPPELMAN, 1999b). To do so EVM requires a thoroughly defined project scope articulated with allocated resources, all shaped into a significant project schedule for performance. Generally these terms are referenced as *bottom-up project baseline plan* (MILOSEVIC and KNOVEL, 2003).

To extend its analysis through the several levels of project management, EVM incorporates specific mechanics to include the use of the work breakdown structure (WBS), performance curves (S-curves), as well as a defined set of performance key components and metrics (MARSHALL, 2007).

The methodology begins with setting up a project baseline. This enables project managers, to determine how much of the planned work you have accomplished as of any point in time in the form of Performance Reports (MILOSEVIC and KNOVEL, 2003, PROJECT MANAGEMENT, 2004).

To achieve such common language, a time-phased sum of detailed tasks to be accomplished, outlining scope, schedule and cost need to be put into place initially (FLEMING and KOPPELMAN, 1999a). The EVM mechanics will monitor any project efficiently against a firm baseline.

In the following subchapters the EVM principles and mechanics will be briefly overviewed.

2.3.1. Scope Management

Scope Baseline defining is essential in accomplishing performance assessment of future works when it comes to using EVM as an evaluation technique. According to *The PMBOK® Guide* (PROJECT MANAGEMENT, 2004), project scope management "*includes the processes required to ensure that the project includes all the work required, and only the work required, to complete the project successfully*". The scope management plan provides guidance on how project scope will be specified, documented, and controlled. The output of the scope management processes will need a sound integration with the three other knowledge area management processes.

The extent and following characteristics of such management plan may be informal, formal, highly or briefly detailed according to the needs of the project. The processes necessary to manage the scope of a project thoroughly are briefly described in this section according to *The PMBOK® Guide* guidelines and adapted to the work developed over this text (PROJECT MANAGEMENT, 2004).

EVM provides a single integrated management control system for projects during their full life cycle, bounding all levels of management with a common performance language. Its integrated approach gives management the ability to accurately measure performance while the project moves from zero to 100 percent completion rate.(MILOSEVIC and KNOVEL, 2003)

Summation of work scope is accomplished using a device called Work Breakdown Structure (WBS) and their subsequent Control Account Plan (CAP). The most important purpose of WBS is providing a method to extensively delineate and then decompose a project into manageable fragments in an integrated fashion. Level one of WBS framework is known as Control Account Plan (CAP), and integrates technical scope, budget and schedule up to the lowest level of a WBS structure. Definition of CAPs is necessary because its aggregation will constitute the total project, being the lowest point at which performance will be attained (FLEMING and KOPPELMAN, 1999a).

2.3.1.1. Define Scope

The first step in scope management is broadly defining the project's scope through the process of developing a description of the project and its major deliverables. The concept of CAP introduced by Fleming and Koppelman is clarified here, as a tool to facilitate scope characterization. (FLEMING and KOPPELMAN, 1999a)

Given that a project has several components within various levels, management control points needs to be set for work package control. These points are called CAP. A CAP is a building block of EVM, a point where project performance will be monitored. The essence of the CAP is to group sequential and homogenous work elements making them manageable (MILOSEVIC and KNOVEL, 2003). The desire result is to focus project manager's attention on fewer but more vital points of their projects making EVM easier to use and more time-efficient. Figure 2 illustrates the CAP concept in EVM (FLEMING and KOPPELMAN, 1999a).

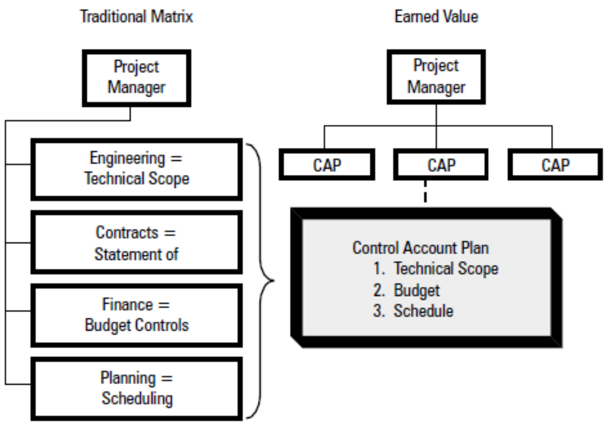

Figure 2 – CAP concept in EVM [adapted from (FLEMING and KOPPELMAN, 1999a)]

2.3.1.2. Create Work Breakdown Structure (WBS)

A WBS framework is used to outline work definition and allocation of resources into a project schedule for performance**.** The Project Management Institute defines Work Breakdown Structure as (PROJECT MANAGEMENT, 2004): "*a work breakdown structure is a deliverable-oriented grouping of project elements that organizes and defines the total scope of the project: work not in the WBS is outside the scope project. As with the scope statement, the WBS is often used to develop or confirm a common understanding of project scope. Each descending level represents an increasingly detailed description of the project elements.*" Figure 3 illustrates an example of an WBS.

Achieving a WBS framework underlies the decomposition of major components within a project's scope into manageable work elements, defined in sufficient detail, capable of supporting forthcoming actions such as project planning, executing and monitoring. Judge whether cost and duration estimates can be established for each work element, at the current level of detail – decomposition of an element that will be produced further down the project's direction, might not be adequate estimated on the current phase.

Breaking down a project into a WBS, helps organize work and it creates a framework from which management of a project can be fully accommodated. WBS facilitates project team members while organizing work into small deliverables that can be manageable and accounted for when it comes to measuring performance(MILOSEVIC and KNOVEL, 2003).

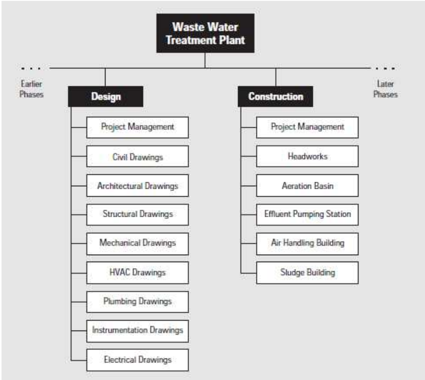

Figure 3 – WBS example [extracted from (PROJECT MANAGEMENT, 2004)]

However, creating a WBS structure may also become a liability, with excessive work required from project's team members while generating new hierarchical trees to help in project monitoring. Large WBS may cause time-consuming and resource-wasting efforts, later in the project (MILOSEVIC and KNOVEL, 2003). WBS templates may be used to increase productivity, while every project is unique, WBSs can often be reused since project's within a given company will resemble another project to some extent having similar or the same project life cycles enabling decomposition into similar or the same deliverables required from each stage (PROJECT MANAGEMENT, 2004).

2.3.1.3. Control Scope

During project execution, is necessary to overview control points and check whether work being performed is within the approved scope and instate changes if needed. EVM, by being a project performance measurement technique also helps in keeping the project under the previously defined scope baseline if necessary.

2.3.2. Time Management

Management processes that lead up to the timely project completion. Activity definition, finding precedence relations to those same activities, allocation of resources to such activities, estimation of duration, are all processes within time management.

2.3.2.1. Project Schedule Developing

Defining a baseline of schedule where activities are defined sequenced and with allocated resources is the first step in time management of a project. A number of techniques is available to enable schedule developing. Common techniques used in the construction industry are, the critical path method (CPM), program evaluation and review technique, (PERT) or Gantt charts, etc.

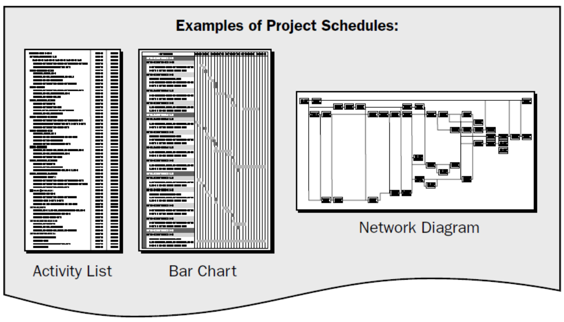

Figure 4 – Examples of Project Schedules [extracted from (PROJECT MANAGEMENT, 2004)]

All these techniques are focused on time oriented objectives and network diagrams when activity durations and precedence relations are known and deterministic. For further reading on the subject see *Total Project Management* (RITZ, 1993). Figure 4 illustrates examples of several project schedules formats.

2.3.2.2. Control Schedule

One of the techniques used to measure schedule performance is EVM. The method helps project manager's in quickly assessing the magnitude of schedule variations. Crucial to project schedule control is to evaluate whether schedule variation requires corrective action, for example a large delay on an activity not part of the critical path may have a small effect on the global project schedule whilst a smaller delay on a critical activity may depend upon prompt action.(PROJECT MANAGEMENT, 2004)

Schedule performance is assessed by correlating the EV to the PV. This can be achieved by computing the variances, the variances percentages, the performance indices and the forecasting parameters at the desired levels of the WBS (ANBARI, 2003). Over the next paragraphs the analysis parameters for time management in EVM will be examined.

<u>Variance Analysis</u>

Schedule variation calculations are generally based on project-to-date data and assess the magnitude of variation to the original schedule baseline. The following formulas are used to calculate both the time variance and the time variance percentage (ANBARI, 2003, PROJECT MANAGEMENT, 2004).

The schedule variance (SV) and the schedule variance percent (SV%) are both "*measures of the conformance of actual progress to the schedule*" with the following formulas:

$$SV = EV - PV \qquad (2)$$

And,

$$SV\% = \frac{SV}{PV} \qquad (3)$$

In both formulas, a 0 value indicates that project performance is in accordance with the baseline. A positive value indicates good performance, and a negative value indicates poor performance.

<u>Performance Indices</u>

The variance indicators can be translated into efficiency indices to reflect schedule performance of any project. The indices are effective for evaluating project status and providing a basis for estimating schedule outcome (PROJECT MANAGEMENT, 2004).

According to Anbari, the schedule performance index (SPI) is a "*measure of the conformance of actual progress to the schedule*" with the following formula:

$$SPI = \frac{EV}{PV} \qquad (4)$$

In the above formula, 1,00 indicates that project performance is in accordance with the baseline and at an efficient rate. A value above 1,00 indicates a highly efficient performance, less than 1, 00 indicates poor schedule performance.

Forecasting Parameters

Forecasting and predicting future outcomes in project management is crucial. The EVM technique incorporates in its methodology forecasting parameters, based on actual project performance and, capable of calculating time of project at completion. Even though EVM has not been extensively used to estimate total time at completion, according to Anbari and using logic similarity of other forecasting parameters in the EVM method, several formulas were achieved. Time estimate at completion (TEAC) and time variance at completion (TVAC) can be calculated based on the time-phased budget, the DAC and the project's performance indicators. (ANBARI, 2003). Again according to Anbari (ANBARI, 2003), following the assumptions made on future project performance and related to the EAC estimates, as explained in section 2.4.3.3., TEAC estimates are calculated according to the following formulas:

- $TEAC_1$ – when current analysis describe previous project performance, as a not good predictor of future project performance, implying that past problems affecting the project will not intervene in future performance, TEAC is calculated according to the equation 5,

$$TEAC_1 = DAC - \frac{SV}{PVRate} \qquad (5)$$

- $TEAC_2$ - when current analysis describe previous project performance, is a good predictor of future project performance, implying that past problems affecting project schedule will intervene in future performance, TEAC is calculated, using the schedule efficiency ratio, SPI,

$$TEAC_2 = \frac{DAC}{SPI} \qquad (6)$$

Another forecasting parameter, the time variance at completion, TVAC, gives an indication of the estimated time frame to which the project will be complete ahead or behind schedule.

$$TVAC = DAC - TEAC \qquad (7)$$

In the above formula, a value below 0 indicates that the project will finish ahead of schedule; a value equal to 0 indicates that the project will be complete according to schedule; finally a value above 0 will indicate that the project will be complete behind schedule.

2.3.3. Cost Management

Management processes that lead up to project completion within the previously approved budget. Those processes being, the ones involved in estimating, budgeting, and controlling costs, and will be briefly overviewed within the appropriate context on the section below.

2.3.3.1. Estimate Cost

Processes involving the calculation of the quantities of various work activities and their respective allocated resources. Detailed estimates, are usually prepared using either the unit quantity method or the total quantity method. For further reading on this subject please *Total Project Management* (RITZ, 1993).The sum of estimated costs assigned to each activity or work package is the funds authorized to execute the project, hence the budget.

2.3.3.3. Control Cost

Status monitoring of the project, is keeping the project on track according to the authorized budget. Cost control also involves keeping track of what is being spent and the amount of work that is being physically executed. Comparing previously assign project funds and project expenditures is key for

not only to the cost control process but the success of the entire management process. And this is where once again, EVM comes in. Cost performance is assessed by correlating the EV to the AC, essentially cost performance parameters express how much is being spent on turning PV into EV. Thus, it can be achieved by computing the variances, the variances percentages, the performance indices and the forecasting parameters at the desired levels of the WBS (ANBARI, 2003). Over the next paragraphs the analysis parameters for time management in EVM will be examined.

Variance Analysis

Cost variation calculations are generally based on project-to-date data and assess the magnitude of variation to the original cost baseline. The following formulas are used to calculate both the cost variance and the cost variance percentage (ANBARI, 2003, PROJECT MANAGEMENT, 2004).

According to Anbari (ANBARI, 2003), the schedule variance (CV) and the schedule variance percent (CV%) are both *"measures of the budgetary conformance of actual cost of work performed*" with the following formulas:

$$CV = EV - AC \qquad (8)$$

And,

$$CV\% = \frac{CV}{EV} \qquad (9)$$

In both formulas, a 0 value indicates that project performance is in accordance with the baseline. A positive value indicates good performance, and a negative value indicates poor performance.

Performance Indices

The variance indicators can be translated into efficiency indices to reflect cost performance of any project, in a report overview. The indices are effective for evaluating project status and providing a basis for estimating cost outcome (PROJECT MANAGEMENT, 2004).

According to Anbari, the cost performance index (CPI) is a *"measure of the budgetary conformance of actual cost of work performed*" with the following formula:

$$CPI = \frac{EV}{AC} \qquad (10)$$

In the above formula, 1,00 indicates that project performance is in accordance with the baseline and efficient. A value above 1,00 indicates a highly efficient performance, less than 1, 00 indicates poor inefficient schedule performance.

The CPI is characterized by The PMBOK® Guide *(PROJECT MANAGEMENT, 2004)* as *"the most critical EVM metric"* measuring cost efficiency ratio for the work already completed.

Forecasting Parameters

Work planning is mainly concerned with decision making affecting future performance. Thus, projections on what will happen are extremely important. EVM method has the ability to forecast both cost and time of the project at completion, using actual performance data, from roughly start to finish of a project. Time forecasting parameters were overviewed on section 2.4.2.2. Below, will be reviewed the cost forecasting parameters, starting with the estimate at completion, EAC and going from there.

EAC and estimate to complete, ETC (the original budget for the remaining work) rates, may vary according to assumptions made on future project performance, the PMBOK® GUIDE (PROJECT MANAGEMENT, 2004) gives project teams, a range of three estimates to choose from, according to adequate project criteria:

- EAC_1 and ETC_1 – when current analysis describe previous project performance, as a not good predictor of future project performance, implying that past problems affecting the project will not intervene in future performance, EAC and ETC are calculated according to the equations 11 and 12,

$$EAC_1 = AC + BAC - EV \qquad (11)$$

And,

$$ETC_1 = BAC - EV \qquad (12)$$

- EAC_2 and ETC_2 - when current analysis describe previous project performance, is a good predictor of future project performance, implying that past problems affecting the project will intervene in future performance, EAC and ETC are calculated according to the equations 13 and 14,

$$EAC_2 = \frac{BAC}{CPI} \qquad (13)$$

And,

$$ETC_2 = EAC_2 - EV \qquad (14)$$

- EAC_3 and ETC_3 – also with past performance intervening in future behavior but this time also incorporating schedule efficiency rate up to this point, the schedule performance index or SPI, (on section 2.4.2.2, equation 4,) , EAC and ETC are calculated according to the equations 15 and 16,

$$EAC_3 = AC + \frac{BAC - EV}{CPI \cdot SPI} \qquad (15)$$

And,

$$ETC_3 = EAC_3 - EV \qquad (16)$$

The variance at completion, VAC, gives an indication, of estimate cost overrun or underrun, at project at completion. VAC is given by the above formula:

$$VAC = BAC - EAC \qquad (17)$$

In the above formula, a value below 0 indicates that the project will experience a cost overrun; a value equal to 0 indicates that the project will be completed according to budget, finally a value above 0 indicates a project underrun.

Another useful forecasting parameter of the EVM method for cost control is the to-complete performance index, TCPI, giving project managers a cost efficiency rate that needs to be met in order to accomplish certain goals. TCPI is given by the formulas below,

- $TCPI_1$ – cost efficiency rate necessary in order to meet the BAC

$$TCPI_1 = \frac{BAC - EV}{BAC - AC} \qquad (18)$$

- $TCPI_2$ – cost efficiency rate necessary in order to meet EAC

$$TCPI_2 = \frac{BAC - EV}{EAC - AC} \qquad (19)$$

2.4. THE EVM METHOD PUT TO GOOD USE – PERFORMANCE REPORTING

Fleming and Koppelman (FLEMING and KOPPELMAN, 1999a), on their extensive EVM research studies, have identified the method's enabling characteristics of channeling a single integrated management control system to all the projects within an organization. Easiness, of use once the method was employed was also related to the method. When the methods outputs were generally available to the management teams, a sound basis for only calling for attention if corrective action was needed is another advantage of a successfully employed EVM method within an organization. Performance reporting associated with the method, displaying only needed information, in form of graphical displays or color schemed thresholds is an effective way, of using the technique methodology within the information busy industry like the construction sector (ANBARI, 2003).

The Project Management Institute explains the concept of performance reporting (PROJECT MANAGEMENT, 2004): "*performance reporting involves collecting and disseminating performance information in order to provide stakeholders with information about how resources are being used to achieve project objectives.*"

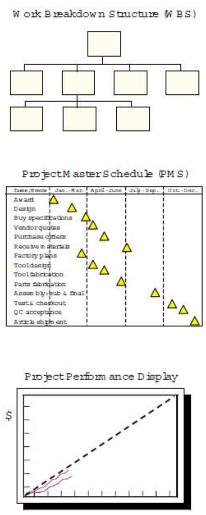

Figure 5 – Illustrative integrated project management approach of the EVM method [extracted from (FLEMING and KOPPELMAN, 1999b)]

The information contained in those reports can be computed through several tools and techniques, one example being the EVM method. It uses status parameters in graphical displays of EV, AC and PV of the project, it uses variances and performance indices to report progress, and finally it can also compute accurate forecasting parameters of future project's performance. This capacity of the EVM to provide accurate data to clarify performance information will be discussed over the next paragraphs. Figure 5 tries to illustrate the integrated project management approach briefly described here.

Status reporting is describing where the project stands at the current date. EVM metrics and their graphical displays using S-curves can be used to give immediate update on project's current situation, giving managers the possibility to assert if corrective measures need to be put into place (FLEMING and KOPPELMAN, 1998). Easy to read information of EVM on the three areas of management, is a quick and effective way to know whether the project is on track.

To achieve EV and AC values, is important to synchronize data and gather all information on invoices, and percentages of work complete (ANBARI, 2003). Graphical displays of how work is progressing let management teams know whether any micromanagement decision making have affected the course of time and cost of the project. Figure 6 illustrates an example of an EVM graphical display.

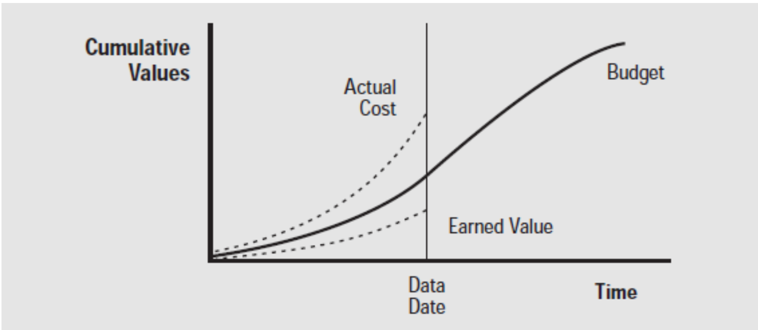

Figure 6 – Illustrative status graphical display [extracted from (PROJECT MANAGEMENT, 2004)]

As an example Anbari (ANBARI, 2003), exemplifies the "traffic light approach", by using meaningful thresholds to the company, project performance can be highlighted through the use of graphical displays with assigned colors according to performance ranges and critical limits, as is illustrated in Figure 7. According to Anbari (ANBARI, 2003), it helps ensure, that when decision making is needed it is highlighted, minimizing tampering and micromanagement. He also proposed a new parameter capable of characterize project health according to both schedule and cost, the critical ratio, CR, given by the formula:

$$CR = SPI \cdot CPI \quad (20)$$

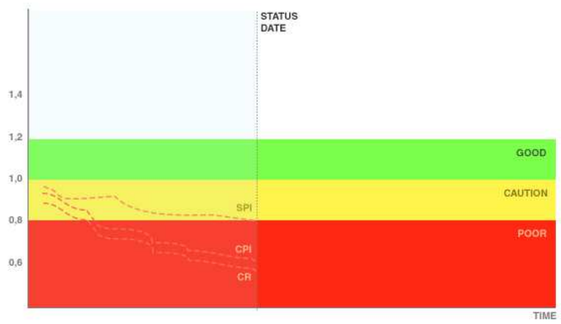

Figure 7 – Example of a the "traffic light approach" graph

Another valuable indicator of trends in performance reporting, are graphs of EAC or TEAC over time. The impact of any corrective actions is clearly reviewed. Figure 8 illustrates a graphical display of EAC evolution over time.

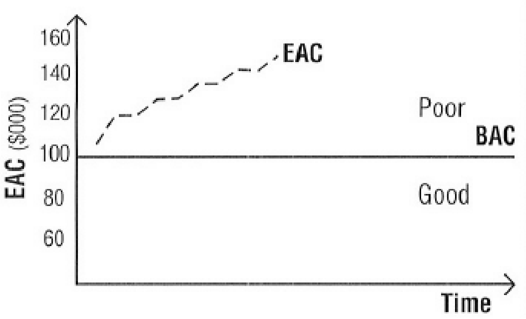

Figure 8 – EAC graph over time [extracted from (ANBARI, 2003)]

2.5. THE SIGNIFICANT ADDITION OF EVM TO CONSTRUCTION PROJECTS

Both Project Management and Construction are challenging subjects, combining the two only makes matters worse (MARSHALL, 2007). Costs overruns of 25 to 33 percent are not uncommon in the industry (PRIEST, 2004) . Construction projects ending in either dispute or litigation have been increasing (LEVIN, 1998). Considering the amount of information about under-performing projects, or common talks about troubled projects in the workplace, construction project managers need effective tools to monitor work progress in order to meet escalating challenges (MARSHALL, 2007). Over the next paragraphs the EVM contribution to effective work progress management in construction will be critically reviewed.

Regarding literature on the subject, Marshall (MARSHALL, 2007) states there are three kinds of knowledge on the contribution of EVM to project success. First, '*propositional*' knowledge research, while logical and meaningful, they are limited to providing theoretical beliefs and assertions: Works of such type (ANBARI, 2003, CHRISTENSEN, 1998, FLEMING and KOPPELMAN, 1998) suggest EVM benefits are felt across all project management stages from planning to monitor. Second, knowledge contribution, '*experiential accounts of project practitioners*', unlike propositional knowledge such research offers empirical evidence of clear contribution of the method towards project success in more than one management stages, based on personal experience and observations. Third and final, '*research-oriented'* work, relying on qualitative methods to make relevant points, they emphasize EVM contribution to project planning and project control (BENJAORAN, 2009, CHOU [et al.], 2010). Thus, Marshall (MARSHALL, 2007) concluded, EVM contributes to:

- project planning;
- to project control, but perhaps more or less so than planning;
- to project management processes that are believed to positively affect project performance.

Another basic utility of EVM is containing cost risk associated with projects. From the owner's point of view reassuring the level of acceptable cost risks, on contracted efforts, while the project is under execution is necessary to lead to success. The literature review on the benefits of EVM to work monitoring will be focused on fixed-price type of contracts for linear construction projects from the owner's point of view since it will be needed while designing a tool applicable to the case study organization line of work, for further analysis on other type of contracts or non-repetitive projects refer to adequate literature such as the ones by author Quentin W. Fleming (FLEMING and KOPPELMAN, 2002).

Mitigating risks on non-repetitive projects, due to their unique nature, using EVM might be a challenge even to the most dedicated project management team. Not an impossible task, since most construction projects fit the characteristics where EVM is applicable (clearly defined objective, high labor content, formalized management structure, cost and time limitations, etc). Formal assessment of work complete might be challenging at first, whereas repetitive projects such as highways, tunnels, storm water systems, sewage systems and pipeline networks might be easier due to their nature, where activities are repeatedly performed from unit to unit, work complete can be easily measures upon work package completion (EL-RAYES and HYARI, 2004, WEBB, 2003).

On horizontal repetitive projects, also called linear projects according to their linear nature of geometrical layout, project progress is measured in terms of horizontal length, i.e. number of work activities completed one after another linearly. Since a horizontal repetitive project has a clearly defined baseline of work packages, most of the basic data needed to perform EVM might be already available on such construction jobs, diminishing the hurdle related to employing a tool or technique from scratch. Work planning and decision making practices, for the class of projects where significant work repetitions are necessary, as is the case with the construction projects promoted by the case study company, pipeline networks or sewage systems, include maximizing the efficiency of resource usage by ensuring continuous, non-interrupted work for all construction crews and it also includes minimizing construction duration to reduce service disruption time during execution. Endowing work continuity, improves overall productivity, by minimizing idle time during frequent movements on site, and also maximizes benefits from learning curve effects. However, research studies indicate that tolerating interruptions of work by constructions crews can lead to shorter project durations. Besides, long disruption times, or having many construction crews working at the same time on the same construction site can cause discontent from several stakeholders, especially if the project is targeted to an urban area (EL-RAYES and HYARI, 2004). Strike a happy medium, when it comes to these conflict objectives is a challenging task and it also requires a strong basis for decision making, this where the EVM method comes into play.

Under a fixed-priced arrangement, the contractors are usually given progress payments based on percentage of work complete, together with what was agreed on the contract, and even though the terminology might not be present this is basic use of EVM. Situations were owners overpay contractors should be avoided since it’s the quickest way to increase the risks. Closely monitoring the physical percentage of work accomplished by the contractors should be the main focus on progress payments arrangements. EVM can mitigate the process.

After analyzing statistical data, Marshall (MARSHALL, 2007), investigated the direct relationship between EVM mechanisms, such as WBS or S-curves, with project success, he also investigated the relationship between EVM use and success in two different types of contracted efforts, fixed-priced and cost-plus. His findings reinsure what has been said by other authors when it comes to EVM conducting projects towards success. Higher the risk associated with the project the more likelihood the project has to benefit from the EVM employment nevertheless lower risk projects such as fixed-priced when compared with cost-plus, will also benefit from a monitoring technique such as EVM while at execution phase.

On the other hand when prices are fixed, performance is more at risk, thus the use of EVM in payment planning in such contracted efforts both incentivizes performance and guarantees work accomplishment, mitigating performance risk. In order to accurately structure payments a PV needs to be established, methods like Schedule of Values or Critical path Method (CPM) could be employed. A time-phase budget baseline comes from the financial schedule submitted by the contractor and approved by the owner; against such baseline project performance can be measured. Unlike cost-plus

contracts, the fixed-priced contracts focus more on schedule compliance, and work accomplishment by the contractor, than on cost mitigation, since the agreed BAC will be what will be paid to the contractor at completion, overlooking contractor price margins, or overheads.

EVM will help owners in scheduling their payments to the contractor monthly and without putting themselves at risk by overpaying the contractor, with EV values being always what is paid to the contractor monthly since is the sum of the physical work complete on site. Even though, payments always need to follow contract agreements and not always there is the situation where the owner pays exactly what he has measured in EV. And, this leads to the problem of the fixed-priced type of contracts and the EVM, not always the AC values are available, because from an owner's perspective the payments are schedule to have a monthly time frame (FLEMING and KOPPELMAN, 2002).

Thus, the problem is in between months there is no AC data available, which prevents important project performance measurements such as CPI. And this is a setback resulting from using EVM in some construction scenarios. In most situations, regardless of terminology it is a cohesive basis for quick decision making in work planning (MARSHALL, 2007).

Another issue related to using EVM to control construction projects and work execution is the ability to incorporate changes to the baseline when project is undergoing. Occasionally, might be necessary to include scope changes, or perhaps project management decides the agreed schedule or budget no longer are adequate with the work being executed, so a change in project baseline is needed and this to be relocated with the EVM method. Different ways to overcome the issue strongly vary from case to case, relies on project management judgment, goals and aims (PROJECT MANAGEMENT, 2004).

Overall, it might be added that EVM method is adequate for work planning decision making.

3
COLLABORATIVE TOOLS

3.1. TO CONSTRUCT IS TO COLLABORATE

Extensive cooperation is required from several organizations when undertaking a project in the construction industry. Unique characteristics of the sector make each project unique, bringing to the table a number of stakeholders, which need to cooperate at different levels of the project lifecycle regardless of their individual practices, resources and aims (HARTY, 2005, XUE [et al.], 2012). While analyzing those unique characteristics each construction project can be seen as a multidisciplinary organization which may or may not continue to collaborate once the project is completed. The transitory nature of the sector and its largely documented fragmentation add to an already complex industry, with low profitability when compared with many other industry sectors (KANAPECKIENE [et al.], 2010).
Another challenge to practitioners is, and part of any cooperative work is the large amount of information circulating among the various stakeholders involved while undertaking a project, making construction an information intense industry. Both fragmentation and high level of information sharing make effective work planning in construction a very difficult task to carry out resulting in poor efficiency of the process (DAVE and KOSKELA, 2009).
Within this context, integrating not only information management tools, but bringing knowledge management concepts into the already existing collaborative platforms of an organization, all within a web-based context. Following that path might enhance work planning and multidisciplinary action, consequently transforming the management of their construction projects (NIKAS [et al.], 2007).
Over this chapter all the concepts above will be discussed through an extensive literature review on the subject matters.

3.2. UNDERSTANDING THE VALUE OF COLLABORATIVE TECHNOLOGIES IN CONSTRUCTION

3.2.1. WHAT IS A COLLABORATIVE TECHNOLOGY?

Team work in construction has existed long since. Across times, the collaborative approach to construction has taken several formats from social knowledge and information transfer to paper-based workflow systems (DAVE and KOSKELA, 2009). The Oxford Advanced Learner's Dictionary defines technology as '*scientific knowledge used in practical ways in industry'* which is quoted here to help define the meaning of a collaborative technology in construction. Concerns on information management and explicit knowledge transfer in work practices have led to the automation of common operations. Thus, such tools function as the backbone of the information infrastructure for coordinating project activities, and has the definition quoted above states, enable practicality and give support to teamwork processes (MARTINS, 2009, NIKAS [et al.], 2007).

Collaboration technologies, as defined by Nikas et al, '*include, at a minimum, a virtual workplace that provides a repository recording of the process of the group, electronic information-sharing (such as though file sharing, email, audio-video conference and electronic whiteboards), meta-information on the entries in the repository (such as date, sequence, and author of each contribution), and easy*

access and retrieval, form the repository'. Advantages found include, easy access, creation, processing, storage, retrieval, distribution and analysis of data with no boundaries of physical location and time, providing a basis for cooperation between geographically disperse organizations (DAVE and KOSKELA, 2009).

The Internet is the key technology among all IT applications for collaborative working in construction. Corporate intranets and collaborative extranets enable relevant information sharing on a web based platform, taking form of an important collaborative knowledge sharing technology in most organizations as a virtual workplace. Such corporate structures store company information such as contact lists, standards forms and databases, company news, procedure manuals, organizations maps, WBS, financial data, procurement databases, project related information, etc. (DAVE and KOSKELA, 2009). In his 2006 research paper van Leuween and Fridqvist (VAN LEEUWEN and FRIDQVIST, 2006), subdivided the current practice of computer support collaborative work in centralized project databases, systems for workflow management, and electronic document management. Problems related to such systems were also studied, describing the centralized data systems as isolated from business processes, and also stating that tools for document management in organizations lack in consistency of information and have redundantly repeated data in several documents compromising information transfer throughout the project's life cycle.

Xue et al. (XUE [et al.], 2012) argued in their research with the retrieval of 83 papers form well known construction journals, indicating that several collaborative technologies have been widely investigated by many scholars from different construction standpoints. Such systems have been applied to different stages of a project cycle and to different organizational levels to ease collaborative work in A/E/C firms. Various summarized examples include: Internet-based systems, wireless technologies, artificial intelligence such as intelligent agent, and virtual inter-organizational systems. The rapid development of IT technologies experienced over the last decade has boosted the advancement of such applications in collaborative work in construction projects. They also proposed a subdivision on the main focuses areas of collaborative IT application in construction work, that being: collaborative design, integrated inter-organizational management systems, and collaborative construction project management.

3.2.2. The Relationship Between IT and the Construction Industry

Information Technology adoption in the construction industry is now and in most cases a routinely used tool and is seen as a problem solving mechanism of the observed fragmentation concerns. As documented, the adoption of such mechanisms improves coordination and collaboration between parties taking part in a construction project, leading to better communication procedures. Its benefits include improving document quality and diminishing of documentation errors, enhancing speed of work and data access, increasing capacity of financial control, overall better information and communication management, simplifying many stages of the construction life-cycle process when successfully instated. (NITITHAMYONG and SKIBNIEWSKI, 2004)

Architecture/Engineering/Construction (A/E/C) firms have seen a growth, over the last decade, in IT spending, (NITITHAMYONG and SKIBNIEWSKI, 2004) indicating that organizations have raised their interest in such systems to ease construction projects. The use and its related time-frame for collaborative IT tools adoption could be explained using Geoffrey Moore's technology adoption curve, adapted to the domain of the construction industry, as seen in Figure. 9. The year 1998, has seen a major breakthrough on the initiation of generalized use of computer supported applications in the industry. Between the same year and 2001, innovators and early adopters tested those applications and found them to bring significant benefits into their projects. Well known construction companies

started to adopt these applications from 2002 to 2003 on their major projects pushing them out to their business partners. From 2004, these applications have seen a wide spread with its adoption by small and medium A/E/C firms, after seeing their benefits on other business companies. Such firms have implemented to some extend these applications in the majority of their projects. Small and medium A/E/C firms can be regarded as the late majority within the technology adoption curve. (NITITHAMYONG and SKIBNIEWSKI, 2004)

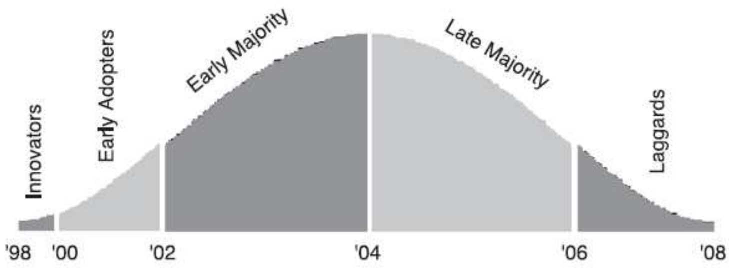

Figure 9 – The technology adoption curve [extracted from (NITITHAMYONG and SKIBNIEWSKI, 2004)]

Practitioners from several professions within construction have experience a number of pressures (DAVE and KOSKELA, 2009). Such pressures indicate a demand in higher productivity from firms and their employees within the multidisciplinary context of the practice. Professionals have been asked to lower lead-time, to lower defects, to lower costs, to reduce environmental impact in order to increase productivity and client satisfaction. Additionally, there are pressures to refine communication among co-workers and to establish accuracy in tools and procedures. The combination of these pressures culminates in the higher usage, by professionals to some extent, of computer supported applications to ease such shears, causing IT spending to observe such growth over the last decade. (GARNER and MANN, 2003)

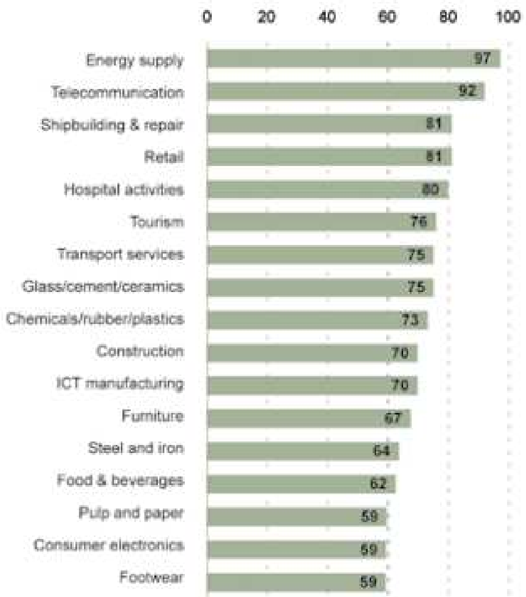

Figure 10 – IT Related Process Innovation in 18 industries [extracted from (W@ATCH, 2010)]

It has also been debated over the years that the construction industry has been relatively slow in adopting the innovative solutions offered by the developments in the IT sector. The construction

industry has always maintained a skeptical view of the IT offerings, while other industries, such as automobile and manufacturing, have successfully used IT to improve the efficiency of its processes. However in the last decade the construction industry has made significant efforts to embrace IT solutions (DAVE and KOSKELA, 2009). Figure 10 illustrates how construction by 2010 is still far behind many industries when it comes to IT related process innovation (W@ATCH, 2010).

3.2.3. Why They Might be the Solution Organizations Are Looking for

New challenges faced by project management teams in construction have prompted companies to seek new solutions in order to regain competiveness. Finding the organizational asset that might keep the company ahead of the competition has proven to be effective if mastered properly. Most of the pressures discussed earlier result of critical mistakes that keep being made project after project. It has been argued over the years, that work planning in construction must require a backbone structure made of both explicit and tacit knowledge to support decision making. Regarding such, during the last decade, the construction industry has taken a step forward embracing the concept of managing construction projects using web-based techniques. Given the nature of collaborative systems they seem the most appropriate solution to identify, capture, process and share the knowledge gathered during a construction project, providing companies competitive advantage if used effectively (DAVE and KOSKELA, 2009, KANAPECKIENE [et al.], 2010, NIKAS [et al.], 2007).

Quoted advantages of online collaborations tools, by Nikas et al. (NIKAS [et al.], 2007) include: '*can facilitate easier management of construction projects, easier access to project information from anywhere at any time, faster transaction time, better transparency in the exchange of project information, savings on project cost, and streamlined construction business processes.*' Benefits from collaboration tools as a form of an information infrastructure might include automational, informational or transformational effects of both operational and management processes, if approached as a sociotechnical system where people, systems and processes form 'culture bed' for it. Thus, with this novel system adoption every component of the human and technological infrastructure of organizations might be affected in a positive way if done accordingly (MARSH and FLANAGAN, 2000, NIKAS [et al.], 2007).

Approaching construction and its future and present collaboration tools from a knowledge management point of view might help on identifying potential benefits for the lifecycle of projects. The unique and dynamic nature of construction projects and their lifecycle pose many opportunities to capture information in the form of knowledge. If this valuable information can somehow be captured, processed and reused for future decision making, it will reduce the waste caused by repeated critical mistakes and improve the process efficiency in general. Although, heavy fragmentation of the industry as a whole makes the knowledge capture process seem utopian, and as a result valuable knowledge is being lost. With the increasing options available to organizations to apply tailored solutions of collaborative knowledge management tools, the process might no longer be seen as utopian but as the strategy to be adopted (DAVE and KOSKELA, 2009, KANAPECKIENE [et al.], 2010). With their research Dave and Koskela identified some key benefits of collaborative knowledge management strategies of applied accordingly to the construction industry:

- '*Enable knowledge transfer*' - construction project lifecycle's require knowledge to flow through various stages, from requirements capture to design, from design to procurement, from procurement to construction and so on, using a collaborative toll to manage knowledge transfer across various stages of a project facilitating smooth transaction between processes.
- '*Capture and reuse project knowledge*' – it has been argued over the years that the industry fails to retain project knowledge for future reuse, regardless of the factors leading to such

failure there is a need for a collaborative management system capable of properly store and keep data knowledge readily available for future reuse.

- ‘*Enable better communication amongst stakeholders*’ – weak communication between stakeholders has been viewed as a to blame for continuous surfacing of problems such as contractual disputes, time and cost overruns and need for rework, an effective collaborative knowledge management tool might help in preventing such miscommunications from happening or at least diminish their negative impacts.

Even though many of the benefits quoted here are well documented through research practices, there is a lack in practical examples of solutions effectively applied to organizations management processes.

3.3. Road To a Successful Adoption

Although collaborative tools for construction project management have experienced a continuous growth in the industry, and both academic and organizations aims are pointed to enhance the potential of such technologies, practitioners usually meet many difficulties when they adopt such systems (XUE [et al.], 2012). Thus, it is understandable that full benefits provided by such systems cannot be fully attained, putting under the scope of future research on how to successfully develop a construction project management collaborative systems suitable to company aims.

There is a great lack of research on the adoption of web-based collaboration in distributed organizational environments. Thus, how to effectively implement and develop such technologies as yet to be studied in future research. Even though the ideal framework for collaborative technology implementation and design has yet to be developed, some researches proposed some guidelines based on previous successful efforts to integrate new technology into the organization’s management process (NIKAS [et al.], 2007, NITITHAMYONG and SKIBNIEWSKI, 2004, XUE [et al.], 2012).

Some research on framework for collaborative technology development in construction has been studied over the past decade. The work by van Leuween and Fridqvist (VAN LEEUWEN and FRIDQVIST, 2006) on concept-modeling proposes a framework model for design information using a distributed object model. The advantages of the model include among others: integration of business processes through data sharing and enhanced consistency and reduced redundancy. Kaklauskas and Kanapeckiene (KANAPECKIENE [et al.], 2010) with their research on knowledge management has proposed knowledge systems suitable for real estate valuation named Knowledge Based Decision Support System for Construction Project Management (KDSS-CPM), considering the economical, political ,legal/regulatory, technological, technical, organizational, managerial, institutional, social, cultural, ethical, psychological, educational, environmental, emotional and confidence needs of stakeholders in terms of both explicit and tacit knowledge as well as building life cycles, making the system capable of providing decision support and form recommendations significant to all the stakeholders by helping to select the best alternatives. Chen and Kamara, (CHEN and KAMARA, 2011) developed a framework for using mobile computing for information management on construction site. The framework includes a concept framework, an application model to identify key factors that determine the use of mobile computing in particular circumstances and their interactions, and a technical model which generalizes mobile computing technologies and gives system designers a clear structure for designing mobile computing systems from a technical perspective.

From most of the literature research done over the course of this work on collaborative tools, it was visible that since the adoption of such technologies is still in very early stages, discussion about their diffusion and deployment in organizational settings cannot be fully investigated. Another concept that was very visible amongst most of the academic papers overviewed was the value of fully

understanding the way an organization conducts its business and their integration level of technology and management processes. Pure focus on technology aspects cannot ensure the success of an information system. The main goal of collaborative tools is to support management activities and decision making. Employment of advanced Its or going beyond practical management needs, without extensive and constant validation of the system being developed lead to many cases of failure. The developer should integrate the management process to be able to shape the system according to organizational needs. Close collaboration with practitioners is a good way to promote successful system's adoption (NIKAS [et al.], 2007, XUE [et al.], 2012).

4
CASE STUDY

4.1. COMPANY BACKGROUND

The proposal of an EVM, in this research, was conducted from a previous starting point, this being a company demand for a computer supported collaborative construction project management platform, incorporating the performance measurement technique.

Public sector owner, and water supply management institution for the municipality of Porto, Portugal, was the organization targeted in this action research scholarly thesis. *Águas do Porto, EM* (AdP) is a municipal entity responsible for maintenance of both the water supply and drainage systems, within city limits. Construction projects, led by the organization, are mainly linked to the hydraulics infrastructures works within Porto's urban setting.

Project procurement method used by the organization, as a public sector owner, are the *fixed-price* contracts. Under the company's scope are three different horizontal repetitive nature projects:

- Water Supply System
- Wastewater Drainage System
- Strom Water System

4.2. PROBLEM DISCUSSION

Minimize construction duration to reduce service disruption during construction, and reduce negative effects on company's image towards stakeholders is a main concern within the organization. Since most construction projects are on contracted fixed-priced arrangements seems relevant that having a tool capable of evaluating process payment structure to incentivize performance, guarantee work accomplishment, and mitigate risks associated with that type of contracts.

Like most construction organizations, the management team has to deal with several projects being executed at the same time. Engineers responsible for work compliance by the contractor usually have on their hands several projects that have to be dealt with in order to keep cost and time on track. Although AdP, was currently using some form of collaborative tool to support decision making, the following issues were identified:

- Existence of a collaborative tool supporting management processes that was not being used to its full extent;
- Static management data from several projects was being captured but did not have the support to be fully processed;

- Control and monitoring during execution lacked a performance analysis technique capable of support decision making.

Thus, a platform capable of comprising information able to support such decision making on work planning needed to be put into practice, incorporating EVM as the performance analysis technique, and also allow knowledge creation for improvements on planning future projects.

4.3. Understanding management Processes

First step towards the successful adoption of such platform, as literature review may qualify, is to understand the organization's practical management processes and their integration with the existing IT infrastructure. Close collaboration with practitioners was the main road taken to better understand how management processes work and to promote a successful tool for work planning. Requirements capture of the tool to be developed was focused on gathering information from across all management processes and also across the several steps of a life cycle of a project within the organization. Figure 11 illustrates the integrated approach of management processes and the project life cycle.

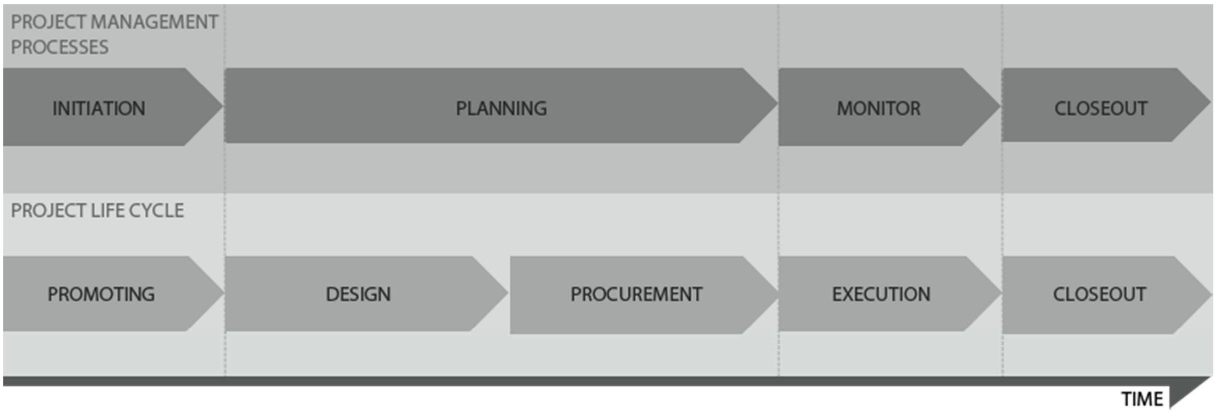

Figure 11 – Project Life Cycle to building a new system at AdP

As explained on chapter 2 a comprehensive basis to which performance of the execution stage will be measured needs to be assembled. To understand how this performance analysis will be put together is best to walk through the overlapping relationship of both project cycles and management processes specific for the organization but similar to most construction companies.

It starts as AdP, the owner will promote a project according to company's policies or from demand of the city's network. Initially, preliminary scope statement is issued and designers are assigned to the project. Next step in the management process is crucial to assemble a cost-time baseline plan to which future performance will be evaluated. Project planning will accompany both the design and procurement phases where the project is fully developed, including final scope planning and definition, cost estimating and budgeting, and future bidding process is prepared. Characteristics of each stretch from junction to junction like any other project of such nature, will be part of the project planning data:

- Length;
- Type of pipe, and its characteristics such as material, DN and PN information;
- Other usage points, such as fire hydrants and branch lines.

Once the procurement stage is over, the project has been assigned a contractor from the winning bid proposal; fixed-priced contract to construct the project is signed, containing among other stakes an

agreed financial schedule to be fulfilled by both parties, and a schedule to be abided by the contractor. Cost-time phased baseline plan is set.

Nature related characteristics to the type of projects promoted by the organization give both the execution and monitor phases a linear flow of work units that need to be followed. Horizontal repetitive projects are the type of projects promoted by the organization as reviewed above in the subchapter 4.1. During execution phase a WBS to read across the three types of projects was developed, and aims at helping control and monitoring by the management team. Definition of the network of streets and stretches was developed in the design phase, and intends to control linearly the number of work units that have been completed during execution. Control was assigned according to the physical display of the network of interconnected pipes, nodes define the stretches, to which each work package needs to be complete in order to finish the job, as is illustrated in figure 12.

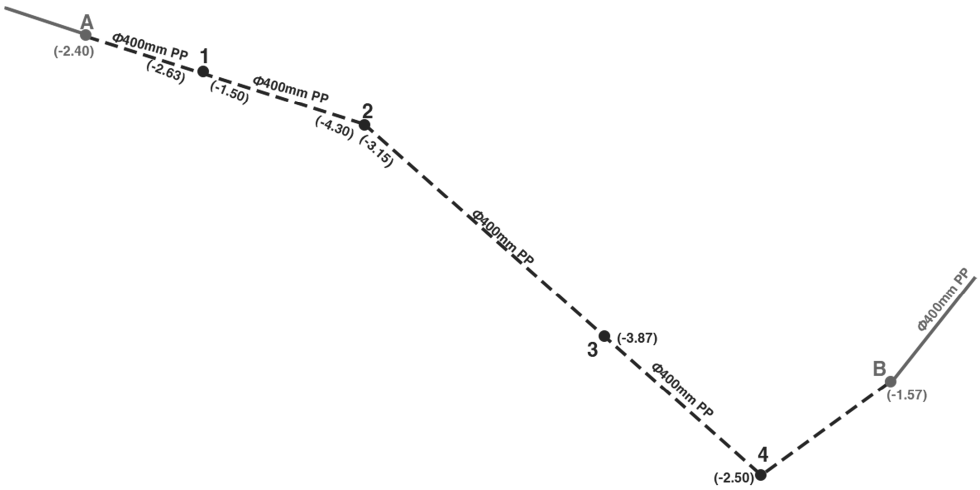

Figure 12 – Extract from a storm water system project

Every stretch has information on their characteristics and that will weigh on the final price to be paid per stretch as explained above. A structure of payments, previously agreed between both parties to reinsure work accomplishment, incentivize performance and mitigate risks associated with fixed-priced contracts is crucial while in execution phase. Such structure will be the foundation of the calculus of the EV, and will be discussed further down on section 4.3.2.1.

Among other practices, project closeout comprises final document management; files containing the new design of the network as an example, from each project there are lessons to be learned and continuous improvements to be made while the projects are still under the planning process.

Scope, cost and schedule control while the project is under execution is mostly done via tacit information and this is where EVM method comes in, thus comprising data into explicit knowledge making the foundation to support work planning and aid in the continuous improvement of project planning, contributing to document management of “lessons learned”.

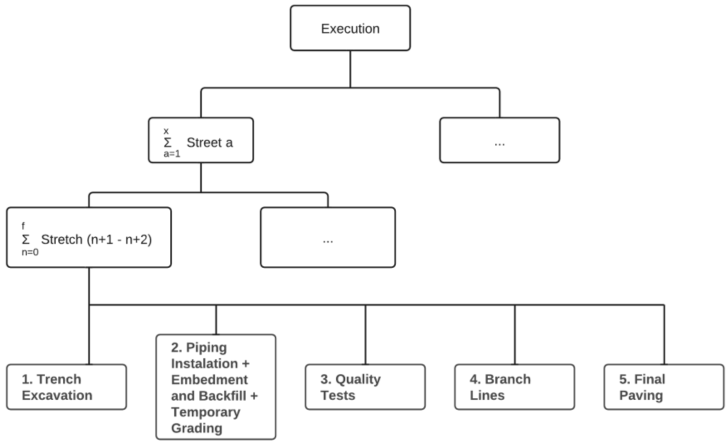

Figure 13 – Execution phase WBS

However, as stated above in 4.2, the last two management processes lack in IT support to their assigned tasks. Even though the structure and the information might be there, there is no technique or method being applied to data to turn such information in to valuable knowledge capable of support decision making both in the present and in the future. Basis for corrective action in active construction projects is missing as well as a basis for lessons learned curve, to enable project closeout data to become an organizational asset for the company.

4.3.1. Existing IT infrastructures supporting work planning

As according to Nikas et al. (NIKAS [et al.], 2007), the creation of a new information tool will always be integrated into or replace part of the existing infrastructures. Thus, it was necessary to evaluate the existing technological base in order to develop the optimal desired EVM performance report system.

IT resources available for performance reporting information management at the organization, are based on commercial packages of database management system, in-house software application systems, word-processing related software, software application for computer-aided design (CAD), project scheduling software and personal information manager system.

Informational data over the project's life cycle is allocated and correlated through an in-house software application system called *Empreitadas* and backed by the database management system developed on *Microsoft Access*®.

Designers get data from the GIS database. Then, project information is developed from word processor software, *Microsoft Word*® and in spreadsheet software, *Microsoft Excel*®, and computer-aided design tools such as *AutoCAD*® and automated mapping software such as *AutoCAD Map*®.

AutoCAD Map® is the interoperable system capable of creating project design pieces and process them into files that the platform *Empreitadas* is capable to read. With that data the platform is capable of creating project related information, ready for the bidding process.

Project scheduling functions are done using *Microsoft Project*® commercial software and other similar. IT communication management among the various project stakeholders is operated through *Microsoft Outlook*®.

4.3.2. Existing Collaborative work planning practices

4.3.2.1. EVM Metrics

Data on EVM is already present in the collaborative in-house developed platform, but the terminology according to the method is not:

PV

Scheduled payments, are essential for baseline set-up, so work execution progress can be obtained. The data comes from the winning proposal submitted by the contractor, and is set up on the database platform in the form of sum to be paid per month – the monthly budget. In essence, the monthly payments that are scheduled to be paid by the organization to the contractor form the PV value.

EV

The EV consists of the authorized work that has been physically completed by the contractor, plus the original budget for that same work.

Such value is automatically calculated by the platform called *Empreitadas* which is, as explained above in 4.3.1, an in-house developed software platform for collaborative project management of the company's projects.

Table 1 – Example of the structure of the daily on-site report for a water supply project

Stretch	Start Node	Finish Node	Material	PN	Length	No. of Branch Lines	Fire Hydrant Type 1	Fire Hydrant Type 2		Trench Excavation	Piping Installation, etc.	Quality Tests	Branch Lines	Final Paving
R. das Antas	1	2	PEAD	PN10	6	0	4	0	Start Date	16/03/12	16/03/12			
									Finish Date	30/03/12	30/03/12			
R. das Antas	2	3	PEAD	PN10	41	0	0	0	Start Date	16/03/12	16/03/12			
									Finish Date					

The files containing project execution information will be crucial to step up the customized Daily on-Site Report fill in worksheet. An example of the structure of such report is represented on Table 1.

Data from construction site is gathered daily by the execution supervisor. The daily reports, as it was described before, are on the form of a worksheets, having info on the characteristics of the pipe network, divide through their nodes by stretches and filled in with the start and finish dates of tasks completed, as well as quantities of those already completed. The work is controlled by stretch "*from node 1 to node 2*" in the network as explained in 4.3 according to the nature of the projects promoted by the company.

The main three different types of construction works performed by the organization have their own structure of On-Site Report since variations on the information inputted are verified to some extent on those three categories of work developed.

Automatized info structure throughout the several reports templates of the many projects developed are possible through coordination between two different software platforms already established by the company, linking the projects particular items to the work to be verified and supervised on site.

Another step in coming up with the EV value is the payment structure as described in section 4.3 and here thoroughly overviewed. The approach was developed considering the similarities between the three main construction projects led by the company. Starting from the common ground between the items present on the three standardized BOQ, the matrix intended to connect the 5 WBS main elements to their referenced priced BOQ work items and establish a lump sum payment for all the contracts.

Time-phased work packs, from 1 to 5 from the WBS elements relate to the BOQ items and are structured in 3 main categories, those being: Trench Excavation, Piping and Branch Lines. A percentage of payment to be assigned at the completion of each WBS element to the contractor as agreed.

The matrix is the structuring element of the whole EVM philosophy created at the organization. The entity has the ability to track all the unitary costs of the small work elements and translate them into a gross value of all the summed work packs. Table 2 intends to illustrate such payment structure.

Table 2 – Example of the payment percentage structure

Work Package	BOQ WORK UNITS		
	Excavation	Piping	Branch Lines
Trench Excavation	15	0	0
Piping Installation, etc.	15	20	0
Quality Tests	0	30	20
Branch Lines	0	30	50
Final Paving	70	20	30

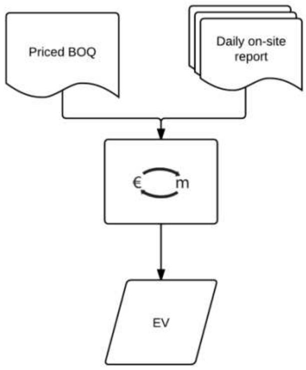

Figure 14 – EV framework

Figure 14 intends to illustrate how the data is processed and finally converted into the EV value. With all the information uploaded to the platform *Empreitadas*, it can successfully calculate the single most important metric of the whole EVM method. Essentially, the system is capable of computing the parameter based on the predefined payments percentages of the WBS work packages, the on-site observations of work packages complete and the units or meters of work actually produced, linking them to their specific unit prices and items on the priced BOQ. The system will sum all the costs of work performed starting from project's initiation date and until the current date when the report is issued.

AC

The AC is the actual cost incurred to convert the PV into EV. Meaning and within the organization context, the AC is the real value paid monthly to the contractor by the organization according to the work completed on site and what was previously agreed. Monthly the management team issues an approved measurement report to the contractor with the sum of the actual cost incurred from that month's work.

Gathering information, both in design and procurement stages is necessary if performance reporting is to be done on further stages, such as execution as it was discussed above. Processing the information necessary to calculate any of this metrics and to be able use the EVM technique, is done while project is undergoing those same stages.

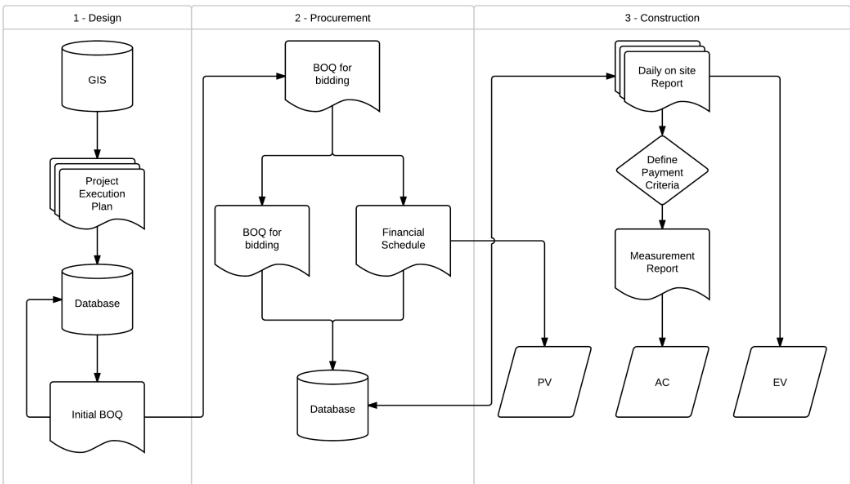

Figure 15 – Framework for the life cycle of Information Flow of the EVM method

Picture 15, tries to summarize what was explained in this case study chapter, and where management processes and project lifecycle processes meet in order to get the EVM reporting method up and running at execution phase.

5

COLLABORATIVE EVM PERFORMANCE REPORT MODEL

5.1. General model requirements

Construction work monitoring and up-to-date status information are decisive points to the fulfillment of company's objectives. Since most of the construction projects promoted by the company are subjected to the contractors' performance and ability to fulfill contract agreements, the supervising team has specific monitoring demands. Accurate feedback tool was needed for supervise and execute corrective actions was required from the data model here designed. The live report data updates were essential to developing a successful work planning performance reporting structure. The proposed model should incorporate the following functions and benefits:

- Integration of data collection interface with EVM Analysis
- Project status overview
- Progress analysis during project's execution
- Work efficiency indexes
- Forecasting and trend analysis
- Prompt and accurate problem identification
- Firm basis for employment of corrective actions if necessary

Additionally, the model should satisfy decision support functions for detecting at an early stage cost trends and schedule overruns, enabling the project manager to successfully address problems by introducing corrective actions to enhance productivity or work rates. Figure 16 illustrates the EVM model against the project life cycle.

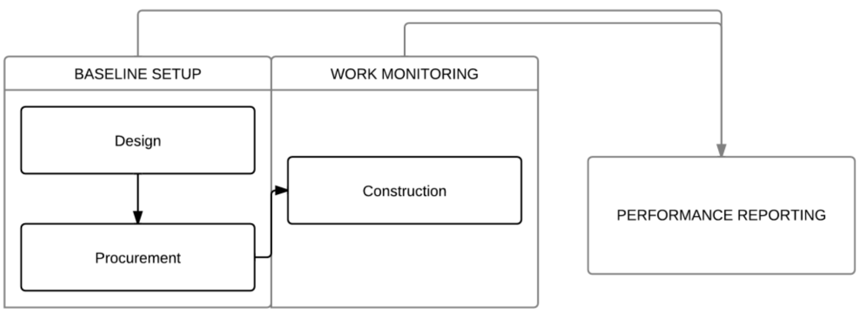

Figure 16 – Framework correlating the standard Project Life Cycle and the EVM model

Another valuable organizational asset resulting from the model's implementation was the foundation for a knowledge management database of the company incorporating information on previous completed projects and capable of enhance future projects promotion and planning. Knowledge management enables the company as the owner to enhance its ability to predict project's problems at an early stage. While on the design and procurement phases problems with future contractors can be avoided if a good basis for problem containing is set and if project managers have the ability to accurate predict what will happen in future, preventing problems from even emerging.

Admitting, the fast pace to which decision making needs to have in order to keep projects on track, both on schedule and time, the average application of the EVM model fails when it comes to fixed-price contracts as overviewed before in section 2.6. Missing the AC related to the EV being measured, cost linked performance indexes cannot be calculated. Typically, payments to the contractor are issued monthly, and in between no real values of AC are available conditioning the performance reporting model ability to give prompt answers to what is being achieved at the construction site.

In order to tackle the missing cost information, two separate EVM performance report were developed:

- Monthly EVM Report – the data is being issued monthly and intends to reflect actual performance of the contractor's execution and also a basis for payments authorization mitigating the risks associated with the type of contracts promoted by the organization and also serve as guidance for future projects;
- Up-to-date EVM Report – live data report capable of being a basis for quick corrective action if necessary to keep project on track, and also inform top-management on how the active projects are behaving in relation both time and cost.

Another issue related to the employment of the EVM method in any project as described on section 2.5 is the manner how changes in time, cost or scope are incorporated into the platform while execution is already undergoing. Even though, the model does not describe the rebase line problem into the platform *Empreitadas*, it is already incorporated a change in financial schedule, DAC if submitted by the contractor and approved by the company. The systems saves past project performance reports made according to the previous baseline starts considering the new information once it has been uploaded to the platform.

5.2. TECHNOLOGY EMPLOYED

The interface required and available to achieve a well-conceived model was decisive at an early stage. Constraints related to resources available were a big structuring path for this model. Platforms used were already at the programmer's disposal, and are mainly commercial use software: Microsoft Access for database storage and management, Microsoft Excel for graph drawing and PDF viewer tool for report visuals delivery.

Automatized and easy accessible report displaying was an imperative variable for the platform's endorsement by its future users, those being: project manager, head engineers, accountants, etc. There was a need to have a program capable of executing a few simple tasks. Combining resource capability, the application available, its platform and the model's requirements, a tread of VBA language code was used. VBA language was already implemented on the Microsoft Access Application available at the company's office. The model for performance reporting was incorporated into the pre-existing collaborative platform for project management *Empreitadas*.

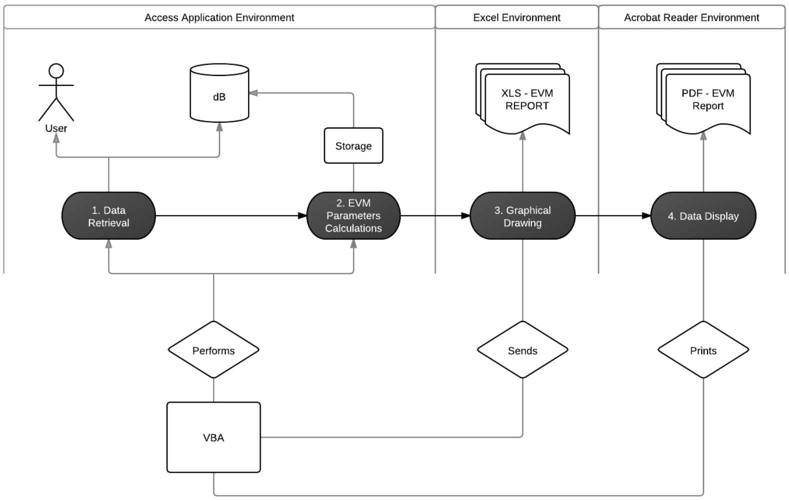

Figure 17 – Collaborative Platform Interface

5.3. Monthly EVM Report

According to the EVM methodology and adapting the performance reporting format of the monthly EVM report to an easy to read document, the pre-formatted excel file for display of the EVM report is comprised in three different parts: overall status reporting, progress reporting and forecasting. Three of the parts are characterized by monthly accurate data collected from the database.

5.3.1. Overall Status Reporting

Graphical information and notes on both cost and time are part of the first section of the monthly EVM report. A quick access to key components of the behavior of the work being performed by the contractor was taken into account while developing the overall status reporting.

Display of the EVM S-curves of the project cost-time behavior also takes part in this section.

<u>Time</u>

- "*Monthly schedule information*" – the .xls file uses the variable TVAC to inform the user on how the project is behaving in terms of schedule on the current month, if TVAC is equal to zero the project is on schedule, if the TVAC is less than zero the project is behind schedule, and if the TVAC is greater than zero the project is ahead of schedule;
- "*Generally*" - the .xls file uses the variable TVAC and its cumulated time data to inform the user on how the project is behaving in terms of overall schedule, if TVAC is equal to zero the project is on schedule, if the TVAC is less than zero the project is behind schedule, and if the TVAC is greater than zero the project is ahead of schedule;
- "Forecasted schedule variation" – by displaying the value for the variable TVAC on cumulated time data, the user quickly is informed on the schedule variance of the time of work complete.

<u>Cost</u>

- "*Monthly budget information*" – the .xls file uses the variable VAC to inform the user on how the project is behaving in terms of cost on the current month, if VAC is equal to zero the project is on budget, if the VAC is less than zero the project is over budget, and if the VAC is greater than zero the project is under budget;
- "*Generally*" - the .xls file uses the variable VAC and its cumulated cost data to inform the user on how the project is behaving in terms of overall cost, if VAC is equal to zero the project is on budget, if the VAC is less than zero the project is over budget, and if the VAC is greater than zero the project is under budget;
- "*Forecasted cost variation*" – by displaying the value for the variable VAC on cumulated cost data, the user quickly is informed on the cost variance of the final cost of work complete.

5.3.2. Progress Reporting

Time Variance

Both cumulated and monthly variances are displayed for schedule differences using the variables SV and SV%.

Schedule Performance Index

Graphical displays of effectiveness of corrective actions, and overall schedule control ability. Simple and direct questions, with color and sign displays of company thresholds on schedule quality performance, and using cumulative data for providing more accurate information:

- "Work progress percentage:" – by applying the index SPI, the value of the pace to which the work is being carried out is presented and the user is informed in which benchmark the value is located according to company management standards and described on Table 6.

Cost Variance

Both cumulated and monthly variances are displayed for cost differences using the variables CV and CV%.

Cost Performance Index

Graphical displays of effectiveness of corrective actions, and overall cost control ability. Simple and direct questions, with color and sign displays of company thresholds on cost quality performance, and using cumulative data for providing more accurate information:

- "Achieved value per unit invested:" – using the variable CPI the report indicates the cost efficiency of work complete and the user is informed in which benchmark the value is located according to company management standards and described on Table 6.

5.3.3. Forecasting

Graphical information and notes on cost and time forecasting parameters are part of the second section of the monthly EVM report. A quick access to key components of the behavior of the work being performed by the contractor was taken into account while developing the overall status reporting.

Time

Graphical displays of effectiveness of corrective actions, and overall schedule control ability. Simple and direct questions, with color and sign displays on forecasted ability of project to meet the DAC, it uses cumulative data to provide more accurate information:

- "*Forecasted Time of Completion*:" – using TEAC variable the .xls file shows the user how long (in months) it will take to complete the entire work scope.
- "*Forecasted Delay:*" – using again the variable TVAC the .xls file defines the negative or positive variance according to the time of completion date in months.

Cost

Graphical displays of effectiveness of corrective actions, and overall cost control ability. Simple and direct questions, with color and sign displays on forecasted ability of project to meet the BAC, it uses cumulative data to provide more accurate information:

- "*Budget at completion will be met?*" – .xls file answers the question by using the variable VAC with "YES" if the value is greater than zero, or with "NO" if the value is less than zero; it also gives the estimated variance in cost;
- "*Estimated cost at completion:*" – using the variable EAC, the file indicates the value of the forecasted final cost of the work contracted;
- "*Estimated cost of work to complete:*" – using the variable ETC the report states the value of cost of work yet to be complete;

5.4. UP-TO-DATE EVM REPORT

Adapting the monthly EVM reporting to incorporate current information on construction site status and work progress information, became essential on making the model a valuable asset to the company. To overcome interrupted information flow from work to office or office to database management system, the monthly report system described on 5.3 was used as groundwork to the up-to-date EVM report model.

5.4.1 TIME MANAGEMENT

Schedule control according to the EVM methodology by The PMBOK® Guide (PROJECT MANAGEMENT, 2004) uses indicators such as SV and SPI to measure the degree of time variations. These indicators, as shown and clarified on 2.3.2.2 do not rely on the AC metric but only on the PV and EV metrics, meaning schedule variation can be measured exactly at this stage on an up-to-date approach.

Accurate and brief analysis of schedule fluctuation was the basis to the structure of the time management section of the report. With an easy reading layout and with an ability to quickly inform users on construction work status were, the starting points of the structure. The system delivers answers to the following time management problems:

- "*Time completion date will be met*?" – the .xls file answers the question using the variable TVAC with "YES" if the variance is equal or greater than zero or with "NO" if the variance has a negative value;
- "*Forecasted Delay:*" – using again the variable TVAC the .xls file defines the negative or positive variance according to the time of completion date in months.
- "*Forecasted Time of Completion*:" – using TEAC variable the .xls file shows the user how long it will take to complete the entire work scope.
- "*Work progress percentage:*" – by applying the index SPI, the value of the pace to which the work is being carried out is presented and the user is informed in which benchmark the value is located according to company management standards.

5.4.2. Cost Management

Actual cost of construction work cannot be determined precisely according to the live data philosophy of the Up-to-date Report. Instead, the EVM methodology was adapted to sustain this philosophy. To closer describe the on-site project's progress, a range of actual cost parameters were established:

- Assuming work progress will mirror current month's budget baseline – α_1;
- Assuming work progress will mirror the ongoing work phase – α_2;
- Assuming work efficiency rate will be maintained – α_3;

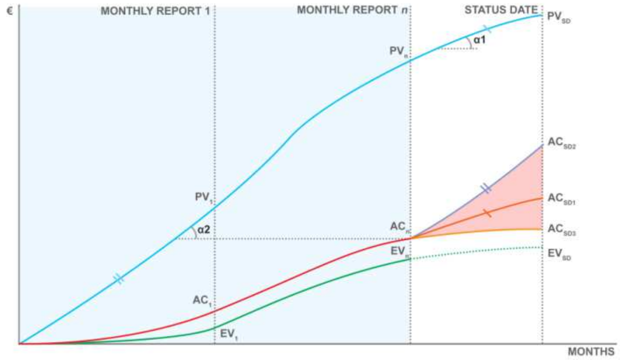

Figure 18 – EVM Graphical Representation for the "Up-to-date EVM Report"

5.4.2.1. Real Cost Incurred Parameter - α_1

According to the parameter α_1, AC incurred from the contractor's production levels, since issuing of the last payment to the contractor until the present day, vary accordingly with the current month's *PVRATE* (if available).

$$\alpha_1 = PVRATE_{cm} (€ / day) \quad (21)$$

$$AC\alpha_1 = PVRATE_{cm} \cdot (CurrentDate - DateofLRI) + AC_n \quad (22)$$

5.4.2.2. Real Cost Incurred Parameter – α_2

While examining the progression of both AC and PV "S-curves", one might find similarities in behavior as it has briefly highlighted in 4.2.1.1. Setting apart both curves is a variance in cost incurred, CV, hence while applying the α_2 parameter and acknowledging works are on a previous stage then the one predicted by the time-budget baseline, for the current date, AC α_2 will have a future behavior similar to the one predicted at the time-budget baseline.

$$AC_n = PV(t) \quad (23)$$

To the time variable t matches a Month i and a corresponding PVRATE. Hence, the corresponding work phase will be located, against the time-phased budget baseline for the project facing real costs incurred up until the last issue of a Monthly Report.

$$\alpha_2 = PVRATE_i (€ / day) \quad (24)$$

$$AC\alpha_2 = PVRATE_i \cdot (CurrentDate - DateofLRI) + AC_n \quad (25)$$

5.4.2.3. Real Cost Incurred Parameter – α_3;

Generally, construction projects have associated variances of both schedule and cost. Acknowledging that those variances might predict future progress behavior and therefore AC incurred is what parameter α_3 tries to incorporate into the Up-to-Date EVM Report. As described in 3, the project's health is outlined by the CR parameter, which incorporates both time and cost effectiveness.

$$AC\alpha_3 = \frac{EV_{cm}^{\ 2}}{CR_{cm} \cdot PV_{cm}} \quad (26)$$

The report's structure for the outlook of the cost analysis follows the structure found for the time analysis, allowing the user a quick overview to verify whether corrective actions are needed so project will meet the BAC. To incorporate the range of three values into the analysis of cost incurred, the maximum and minimum values where included:

- "*Budget at completion will be met?*" – .xls file answers the question by using the variable VAC (VACα1, VACα2, VACα3) with "YES" if the minimum value among the three values is greater than zero, or with "NO" if the minimum of the three values is less than zero;
- "*Forecasted Cost Variance:*" – once again using the variable VAC (VACα1, VACα2, VACα3), the file indicates the maximum and the minimum values with a budget under run or a budget overrun according to the budget at completion;
- "*Estimated cost at completion:*" – using the variable EAC (EACα1, EACα2, EACα3) the file indicates which are the maximum and the minimum values of the forecasted final cost of the work contracted;
- "*Estimated cost of work to complete:*" – using the variable ETC (ETCα1, ETCα2, ETCα3) the report states which are the maximum and the minimum values of cost of work yet to be complete;
- "*Achieved value per unit invested:*" – using the variable CPI (CPIα1, CPIα2, CPIα3) the report indicates which are the maximum and minimum values according to the range of real costs calculated;
- "*Cost efficiency rate necessary to meet budget at completion:*" – using the variable TCPI the report indicates the maximum and minimum effort values needed to meet the contracted budget.

6
SYSTEM'S IMPLEMENTATION AND EVALUATION

6.1. EVM Report Put Into Practice

The collaborative platform for performance reporting was deployed and tested for a water supply system project. Both EVM report formats were tested.

Only one project was put to the test due to the lack of information available to employ the model, especially the daily on-site update scheme. The studied project located on the west part of the city and coded as "PC142/2011 – Remodelação da Rede de Abastecimento de Água nas Ruas Paulo da Gama, Gaspar Correia, Álvaro Gomes, Estevão Gomes Pedro Escovar João Baptista Lavanha e Senhora da Ajuda" with a BAC of 394.870€ and a DAC of 90 days. Table 3 sums up the contract information on the project.

Users can choose on the application *Empreitadas* between the monthly format and the up-to-date format. The monthly model will be overviewed first. Units used for cost measurements was € and for time measurements was months and days for the monthly report and for the up-to-date version respectively. All the data below, including table or graphical displays, was extracted from the report files. Across the two formats the assumption leading to forecasting parameters determination, as described in sections 2.4.2.2 and 2.4.3.3 was that previous project performance would best estimate what will happen in the future.

Table 3 – Information on the case study project

Type	Water supply system
Location	*Rua Paulo da Gama*, Porto
Contract	Fixed-priced
Budget	394.870€
Duration	90 days

6. 2. Monthly EVM Report – PC142/2011

Post implementation review on whether the calculated values were adequate to the real behavior of the project was necessary. Over the next sections the values calculated for each monthly performance report, 1, 2 and 3 will be reviewed. However, the results from report 1 were discarded. At this stage, percentage complete was 6,60% and as explained in section 2.1.3.1., the EVM method only starts giving suitable performance measurements as early as possible as 15% percentage complete, being that the acceptable threshold for starting considering the method's projections.

Below is shown in this text the latest monthly performance report made available for the project *PC142/2011* – month 3. General graphical display of time and cost show the color red meaning project is over budget and behind schedule. General information on project's scope and baseline, BAC and DAC, is displayed. Time elapsed since start of construction work and percentage complete are also displayed. Additional information on units of project complete is also displayed against number of units required by the contract and baseline. Figures 19, 20, 21 and 22 illustrate the pages of the report.

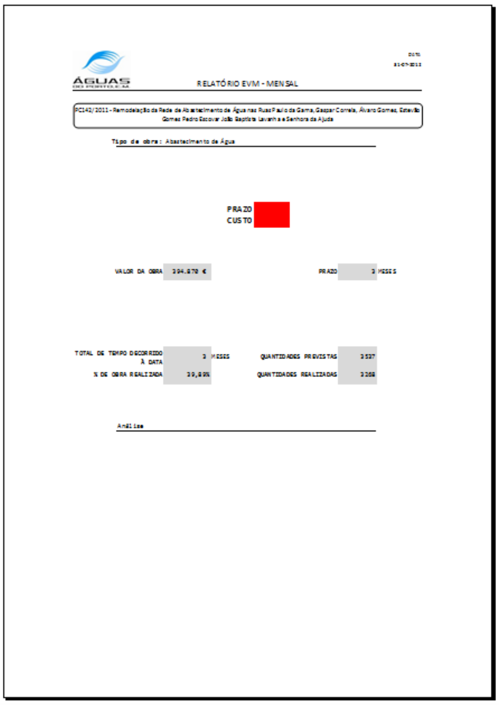

Figure 19 – Monthly EVM Report Cover for PC142/2011-MONTH3

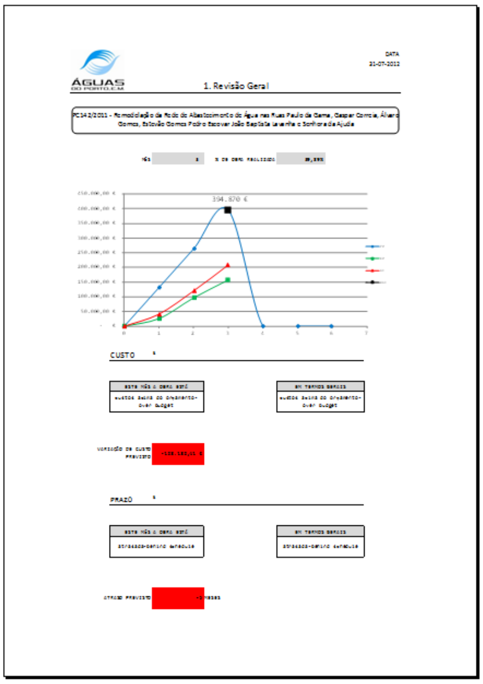

Figure 20 – Monthly EVM Report Page 1 for PC142/2011-MONTH3

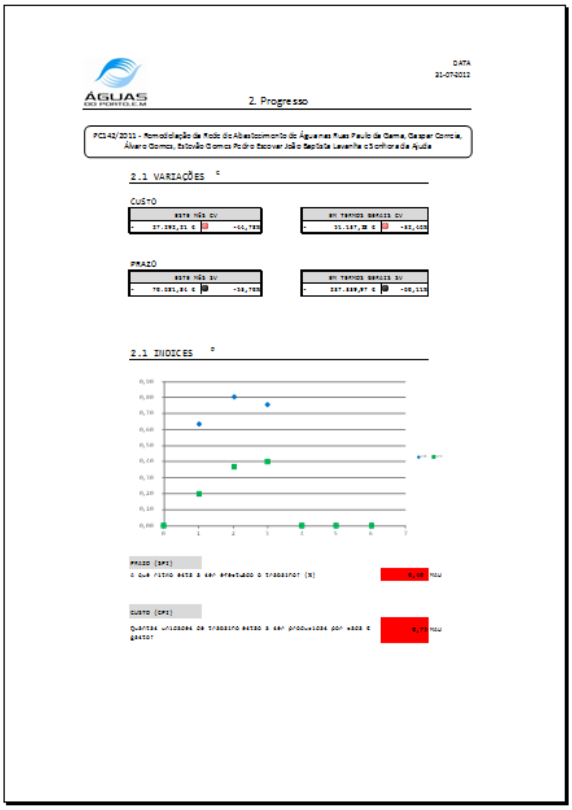

Figure 21 – Monthly EVM Report Page 2 for PC142/2011-MONTH3

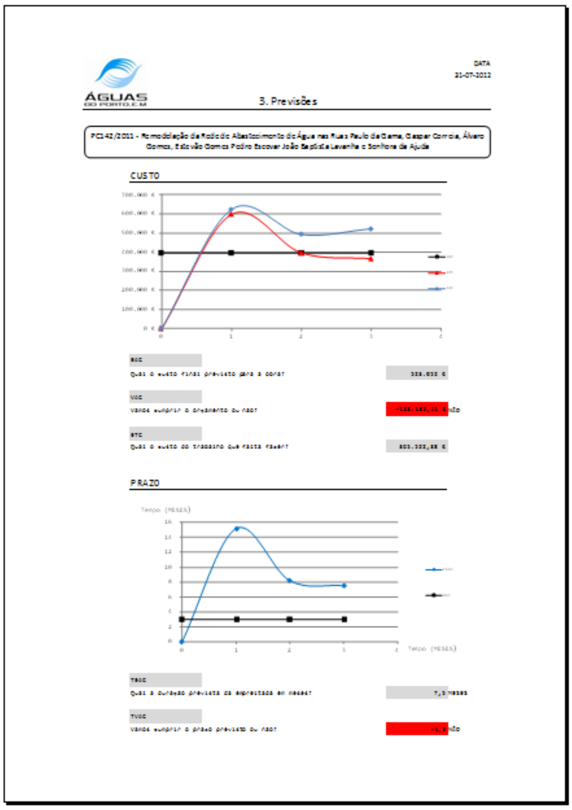

Figure 22 – Monthly EVM Report Page 3 for PC142/2011-MONTH3

6.2.1. Overall Status Reporting Results

First thing that pops into mind while overlooking both Table 4 and Figure 23, the graphical display of the EVM S-curves is the fact that the project is behind schedule even in its final third month with only 39, 89% of work completed. Judging by the construction site status and the field supervisor information the numbers delivered by the EVM method are not far from the truth.

Both months exhibit a poor project performance in both time and cost matters. Both reports have implied that the project is behind schedule and over budget. Such, fluctuations over the two months will be analyzed further down in sections 6.1.1.2 and 6.1.1.3. Decisions to be made according to the information given by the reports will be also overviewed on section 6.1.1.3.

Table 4 – Overall Status Reporting Results (cumulative data) PC142/11

	PROJECT PC142/2011	
MONTH	2	3
Percentage Complete	24,46%	39,89%
TIME	behind schedule	behind schedule
Expected TIME Variation	5,2 months	4,5 months
COST	over budget	over budget
Expected COST Variation	97.482,62 €	128.182,41€

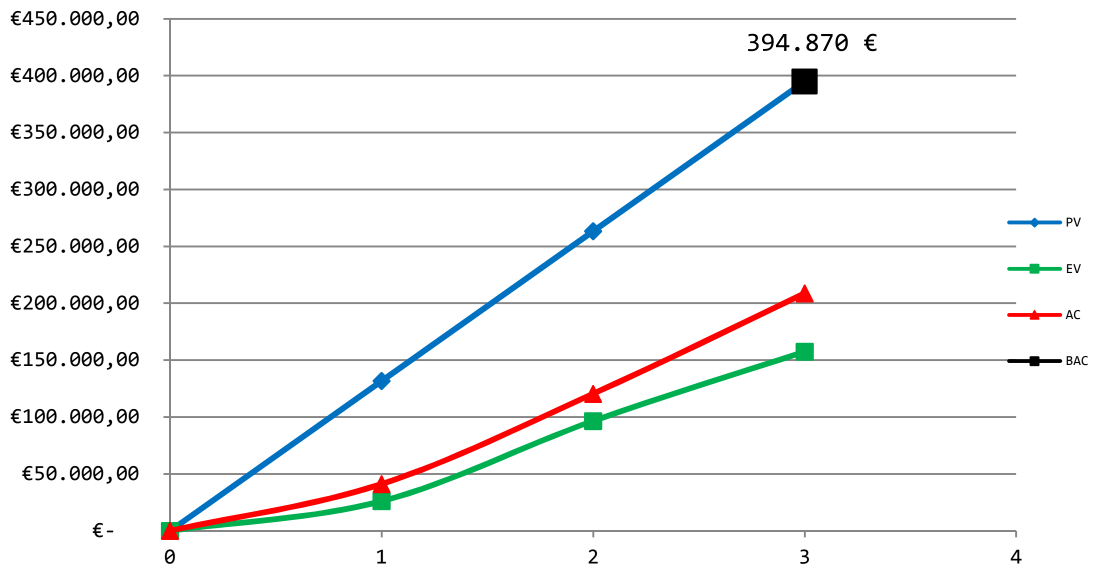

Figure 23 – Graphical Display of the S-curves for the EVM report: PC142/2011-MONTH 3

6.2.2. Progress Reporting Results

Cost

Looking at the cost values (first and second row of values from Table 5) it is visible that budget deviations are increasing as work evolves, which means the difference between what is being achieved by the contractor and what is actually being paid is increasing (CV% from -24, 69% on month 2 to -32, 46% on month 3), resulting in higher risks for the company, since according to the EVM method the contractor is being overpaid.

Cumulative CPI data also verifies what was stated before, it is getting more expensive to turn the PV into EV, meaning on month 3, the output of each € of money invested is only 0, 75 – very poor performance. Even though project cost performance picked during the second month, it went back to a very poor performance again on the third month (Figure 24).

Time

In terms of schedule values is better to look and the percentages. Looking at the evolving variations of the SV% (Table 5) is clear that even though looking at only monthly data the time results are worse, generally looking time efforts are being picked up by the contractor probably because of finishing piping installation in many of the stretches, since the work load of most of the excavation is only being counted when the contractor finishes, piping installation of those same stretches.

Looking at figure 24, it is clear that schedule behavior is improving as time evolves, from an SPI of 0, 37 on month 2 to a 0,40 SPI on month 3. Even though, non-cumulative data shows a slight setback between month 2 and month 3, less schedule improvement, than during the time frame between the first and the second months (Figure 24).

Table 5 – Progress Reporting Results PC142/11

PROJECT PC142/2011				
MONTH	2		3	
	Non-Cumulative Data	Cumulative Data	Non-Cumulative Data	Cumulative Data
CV	-8.730,72 €	-23.845,07 €	-27.292,21 €	-51.137,28 €
CV %	-12,38%	-24,69%	-44,78%	-32,46%
SV	-61.082,83 €	-166.658,13 €	-70.681,84 €	-237.339,97 €
SV %	-46,41%	-63,31%	-53,70%	-60,11%
CPI	0,89	0,80	0,69	0,75
SPI	0,54	0,37	0,46	0,40

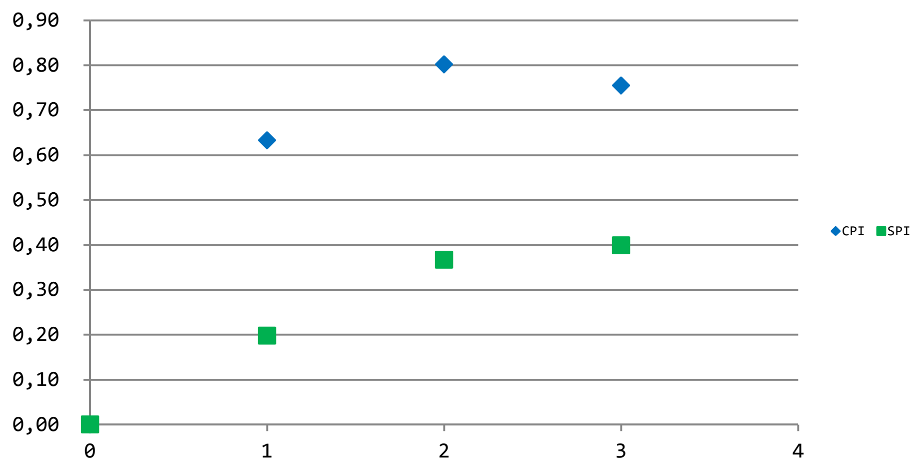

Figure 24 – Graphical variation of the cumulative CPI and SPI values for the EVM report: PC142/2011-MONTH 3

Table 6 – CPI and SPI thresholds

Indexes	Project Performance	Color Scheme
CPI and SPI > 1,05	Excellent	
1,0 < CPI and SPI < 1,05	Good	
0,95 < CPI and SPI < 1,0	Average	
0,85 < CPI and SPI < 0,95	Poor	
CPI and SPI < 0,85	Very Poor	

6.2.3. Forecasting Results

As overviewed on section 2.4, graphical displays of variations over time might provide valuable indicators of trends to project behavior, and future basis for improvement. Forecasting parameters, as also stated on chapter 2, have better insight and more accurate data if calculated using cumulative information.

Table 7 – Forecasting Results (cumulative data) PC142/11

PROJECT PC142/2011		
MONTH	2	3
EAC	492.353 €	523.052 €
ETC	395.764,08 €	365.522,38 €
VAC	-97.482,62 €	-128.182,41 €
TEAC	8,2 months	7,5 months
TVAC	-5,2 months	-4,5 months

<u>Cost</u>

First three indicators on Table 7, give us information on what will be the final costs for the project, and if whether they are far off or not from what was previously anticipated. In section 6.1.1.2, it was

stated that over time payments issued to the contractor were drifting apart from the value of the real work already completed. Thus, parameters EAC and VAC confirm the same, costs are escalating, and budget at completion is furthering itself from the original BAC in the second month by a plus value of 97.482,62 € and by the third and what should be the last month of execution by a plus value of 128.182,41 €.

Figure 25, gives a clear interpretation of the evolution of the cost forecasting parameters against the BAC. EAC was furthering itself from the BAC on month 1, even though forecasting at this stage needs to excluded as explained in section 6.2, we can imply that the impact of cost corrective action had its toll from month 1 to month, because it is obvious by the graphical displays that the EAC value decreased again, getting closer to the BAC. Though, between month 2 and 3 cost performance worsened. From the ETC curve it is obvious that when time moves onward, the ETC value will decrease, what is interesting to extract from it is the rate to which it is processed, showing how long it is taking for the PV to become EV in terms of non-cumulative data. Time between month 1 and 2 saw a higher pace than the one experienced between month 2 and 3. All of the above reflects and endorses what was said in section 6.2.2.

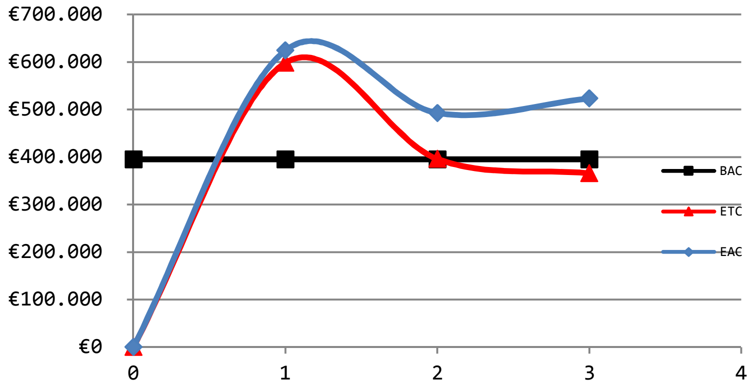

Figure 25 – Graphical Display of BAC, ETC, EAC over time: PC142/2011-MONTH 3

Time

Forecasting parameters reflect what was said of schedule parameters on section 6.2.2. Schedule performance was better between month 1 and two probably due to the impact of corrective actions such as allocation of more resources on site by the contractor. Month 3 saw a setback in terms of corrective action effectiveness on schedule achievement.

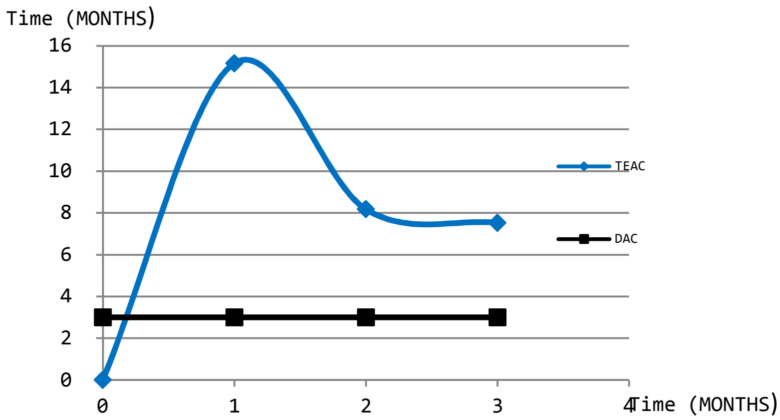

Figure 26 – Graphical Display of TEAC and DAC over time: PC142/2011-MONTH 3

6.3. UP-TO-DATE EVM REPORT - PC142/2011

Problem encountered while the implementation was being reviewed, and as in many organization working with freshly employed new work practices, specially IT related as described in chapter 3, there was a lack of data, more specifically the time dates from the daily-on-site report, available on the platform, meaning information from the construction site was not being uploaded to the system, inhibiting the platform form computing the EV value.

Hence, the implementation review of the up-to-date EVM report will be focused on understanding if the proposed model of three parameters for AC estimation is adequate and not on the forecasting parameters EVM method gives. Even though AC are being estimated for a fabricated EV value, it was found necessary to evaluate the range of AC values the model would propose for this project, in order to understand if the model might give reasonable values.

Thus, to test the up-to-date model, there was a need to select both a time-frame and an EV related to the previous EV data available. Since, construction was still undergoing, the time-frame selected was day 120 since the beginning of the project execution, meaning it would an up-to-date EVM report mirroring the fourth monthly report for the project PC142/2011.

An EV of 215.000 € for day 120 was selected, as it was related to previous values registered for month 1, 2 and 3, and was found to be a reasonable value to represent construction work load done up to that point. As it was explained in section 5.3 the format of the up-to-date report is divided into time management and cost management. Another irregularity to the EVM model, was the fact that construction was still undergoing after the DAC time date, leading to what is seen in Figure 27, on the PV curve and on the $AC_{\alpha 1}$ curve, because no time-phased budget-baseline was set for that fourth month.

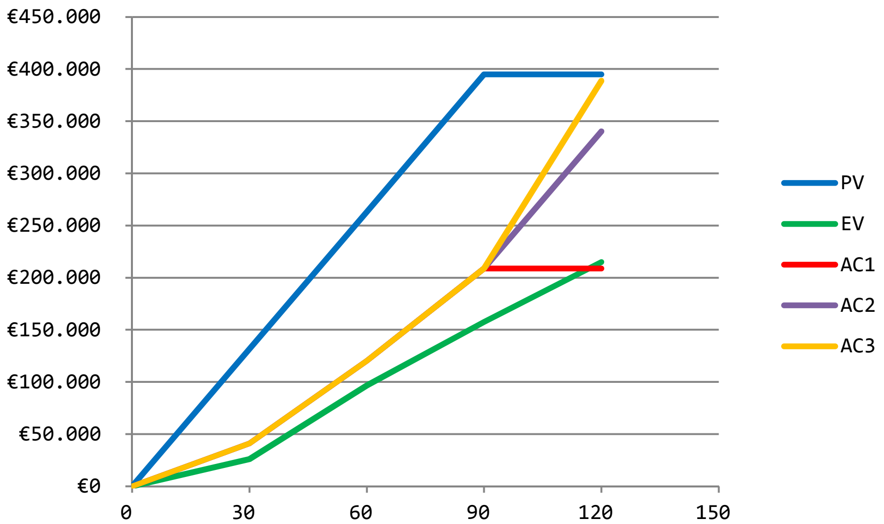

Figure 27 – Graphical Display of the S-curves for the up-to-date EVM report: PC142/2011 - day 120

Second thing that comes to mind while examining the EVM graph, even though these are not real costs incurred, or real work already accomplished by the contractor, is the escalating pace to which the costs have expanded since DAC has already fallen behind by 30 days that could be one explanation for such escalation. Turning the PV into EV is getting more and more expensive by the day, this is what means, once again understandable since “time costs money” and extendable construction times lead to huger costs incurred by the end of the project.

Now, that one parameter has already being cut off from this evaluation, and for reasonable matters, a closer look at estimating parameters α_2 and α_3 is needed, in order to understand what both scenarios are trying to say about project health and future decision making. Beginning with α_3 and then continuing to α_2.

Behind the calculation of the $AC_{\alpha 3}$, is an assumption that "work efficiency rate will be maintained". According, to section 5.3.2.3, the α_3, acknowledges, the variances of schedule and cost, might predict future progress, focusing on the last validated data for the CR parameter. Agreeing with what has been previously said about the CR parameter, in section 2.5 it focused on an efficiency rate that considers both the negative cost performance to date, and the need to commit with the schedule baseline, hence this can be viewed as the "worst case scenario": Since, it was considered that both schedule and cost parameters have the same weigh, and from formulas 20 and 26 it is visible that this parameter would give an pessimistic review of the project performance. Whether CV% and CV (Table 8) given by this parameter are within acceptable tolerances is arguable since this evaluation is being based in fabricated EV values.

On the other hand parameter α_2, follows the assumption that "work progress will mirror the ongoing work phase". According, to section 5.3.2.2, the α_2, acknowledges that construction work is on a previous stage at this point and future behavior will be predicted by the time-budget baseline for that previous phase. Hence, it gives a more tamed view on the project scenario, incorporating the CV%, CV and CPI on cumulative data on a more tolerable range.

The range of AC given by both parameters is of about 40.000€, again an acceptable threshold when comparing to the BAC.

Table 8 – Explanatory Up-to-Date EVM Report Evaluation results table - PC142/11

PROJECT PC142/2011								
	2		3		4			
					α_2		α_3	
MONTH	Non-Cumulative Data	Cumulative Data	Non-Cumulative Data	Cumulative Data	Non-Cumulative Data	Cumulative Data	Non-Cumulative Data	Cumulative Data
% complete	24,46%		39,89%		54,4%			
EV	70.541 €	96.589 €	60.941 €	157.530 €	57.470 €	215.000 €	57.470 €	215.000 €
AC	79.271 €	120.434 €	88.233 €	208.667 €	131.623 €	340.291 €	180.024 €	388.691 €
CV	-8.731 €	-23.845 €	-27.292 €	-51.137€	-74.154€	-125.291 €	-122.554€	-173.691 €
CV %	-12,38%	-24,69%	-44,78%	-32,46%	-129,03%	-58,27%	-213,25%	-80,79%
CPI	0,89	0,80	0,69	0,75	0,44	0,63	0,32	0,55

If management judgment on this project review considers it to be adequate to the real project scenario, the report can be basis for oblige the contractor to allocate more resources to the site, or get more construction crews on site working at the same time. Since fixed-priced contracts have the advantage of maintaining the agreed BAC as overviewed in section 2.6, the cost estimation relate what will happen at project at completion. Figures 28 and 29 illustrate extracts from the up-to-date performance report from day 120 of project PC120/11.

OVERALL REVIEW
behind schedule

Time completion date will be met?	NO	
Forecasted Delay:	5,5 months	
Forecasted Time of Completion:	8,51 months	
Work progress percentage:	0,54	VERY POOR

Figure 28 – Extract for the Time Management forecast for the Up-to-Date EVM Report PC142/2011-DAY 120

	MIN	MAX
Bugdet at completion will be met?	NO	
Forecasted Cost Variance:	230109 € ;	319002 €
Estimated cost at completion:	624979 € ;	713872 €
Estimated cost of work to complete:	409979 € ;	498872 €
Achieved value per unit invested:	0,55	0,63
Cost efficiency rate necessary to meet budget at completion:	3,30 ;	29,11

Figure 29 – Extract for the Cost Management forecast for the Up-to-Date EVM Report PC142/2011-DAY 120

7
CONCLUSION

7.1. CLOSING NOTES

Work planning and decision making are well proven to be difficult tasks, the EVM method has sized to be an aid by introducing an accurate feedback technique if mastered properly. What a collaborative tool can to do to also aid in the management process is to ease the introduction of the EVM method into existing work practices.

Several construction organizations already employ the EVM philosophy without even knowing. Hence the introduction of such system has proven to be not so difficult if some form of monitoring is already employed, as in most cases. The EVM method by itself might prove to be quite difficult to ease into a construction organization. The key to soothe the introduction of the analysis technique is to use of an IT infrastructure capable of process data from beginning to end of the project's life cycle. To prevent failure of new IT based techniques, the level of IT maturity in the organization is central. If some form of collaborative management processes are already backboned by an IT platform the more likely is to be successful the introduction of a new component to the same system, hence a tool for EVM based report. Another aspect capable of make or break the successful adoption of a new system is the level of understanding of management processes within the organization by developers of the system. Full understanding of how work processes are ensemble together from 0 to 100 % of a project development has proven to be the path to take.

All things considered, the collaborative tool here developed at AdP, might be considered to be successfully integrated into the existing system, even though the level of use is still at a very low rate, since data upload to the system is not done in a consistent manner. The technique chosen for data analysis, the EVM method, since the projects promoted by the company are fixed-priced basis, meaning risks or costs overruns are diminished, the responsibility of the EVM method in this case, has proven to be more on schedule control basis and not really focused on cost at completion estimation. From an owner's point of view, with concerns on schedule compliance by the contractor, the EVM feedback method, can serve as a basis for overseeing on how the contractor is allocating resources and if work continuity of construction crews should be maximized.

Any construction organization that wishes to incorporate a feedback tool for decision making and work planning might choose the EVM method, since it has proven to be effective in order industries developing projects with much of the same characteristics, like the software industry that also develops projects with a non-repetitive nature. The model here developed was designed to be incorporated to an organization working as a promoting company on the basis of fixed priced contract agreements. The metrics to which were already accounted for so any organization with a similar approach can easily apply the reporting model here developed.

7.2. FUTURE RESEARCH

Enhancing usability of a collaborative performance reporting tool should be a main concern for future developments with this field of study. Using a web-based application instead of commercial software packages would increase the usability and applicability of such a tool. Holding back the use of the reporting model, to a further extent is the break in information flow between the construction site and the information platform, a web-based mobile computing system could be developed to tackle the issue.

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