ENHANCED EARNED VALUE ANALYSIS – IMPROVING VISIBILITY AND FORECASTS IN PROJECTS BY INTRODUCTION OF CLUSTERS

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Abstract
Earned Value Analysis (EVA) is a performance measurement tool that has been used in project management for decades. It is simple to use, but at the expense of its simplicity it has its limitations, such as an assumption that variance in one task can be extrapolated to all other tasks in the project. In this paper, Enhanced Earned Value Analysis (EEVA) is presented. EEVA is an extension to EVA and Earned Schedule (ES) by the introduction of clusters. The clusters provide EEVA with the capability to make new estimates more reliable, as extrapolations on actual data gathered, only is done to a selection of tasks sharing the same resources. It will also provide a higher visibility in projects, that helps when looking for root causes of deviations. The method of EEVA is developed based on a thorough search through literature, and the paper will present at stepwise description on how EEVA can be carried out. A preliminary validation of the model is being carried out through the application of EEVA to a test project. Because of confidentiality reasons, the results from this is presented in the appendix. As defined by the end of this paper, additional validation activities is needed to fully validate the model. However preliminary perception of stakeholders involved, suggest an initial validation of the developed model.

Keywords
Earned Value, Project control, cost forecasting, duration forecasting, clusters.

Introduction
Today there is a race between organizations either to be the first to develop, have the best, or the cheapest solution. To manage the pressure of this growing competition, organizations has embraced the project form. The overall goal of a project is to meet the requirements within time and budget. To accomplish this, measurement of project progression and associated estimates of cost and time at completion are conducted. Earned Value Analysis (EVA) is a project management tool developed in 60's, and it is used for scope, cost and schedule control. It has been stated as the most important measurement tool of choice in literature and global standards (Anbari, 2003; Evensmo & Karlsen, 2005; Rozenes, Vitner, & Spraggett, 2006; Willems & Vanhoucke, 2015). Projects are in many forms, and they span from small deterministic projects, to major development projects, where tasks are defined as the project progresses. Tasks in project spans from administrative tasks to tasks related to development, where uncertainty of estimates is high. The fact that EVA relies on a deterministic approach and that variances in one task is extrapolated to all other tasks in the project, challenges the reliability of estimates provided by EVA.

The objective of this paper is to present an Enhanced EVA, EEVA, to improve the accuracy of cost and schedule forecasts in all types of projects. EEVA will also increase project managers visibility in projects, and make it easier to identify the troubled areas, if the project is not delivering to its expectations. The next sections are organized as follows. First a literature review is conducted, here relevant literature on EVA will be presented, showing what work has been addressed in this area earlier. Framework and theoretical presentation of EEVA will be presented in the next section. The last section describes an implication for engineering managers. A case study was also conducted to validate EEVA. Given the confidential nature of the pilot project, this is presented in the appendix.

Literature Review
Over the years the literature on project management has grown big, but still many projects are troubled (Bloch, Blumberg, & Laartz, 2012; Jones, 1995; Keil & Mähring, 2010; Williams, 2005). Mir and Pinnington (2014) found empirical evidence of the correlation between the performance of project management and project success. One of the keys to project success is control of the project in terms of cost, schedule and scope, also called the iron

triangle(Pinto & Slevin, 1988; Shenhar & Dvir, 2007). If a change is made in one, it will have an impact in at least one of the other two.
In the 1960's the US Department of Defense (DoD) had problems with contractors running over budget, and being behind schedule, and no one had been able to establish an acceptable cause-effect relationship between cost, schedule and scope (Warhoe, 2004). In 1967 the US DoD adopted a Cost/Schedule Control Systems Criteria (C/SCSC), that actually, in a basic form, can be traced back to industrial engineers on the factory floor in the late 1800s (Anbari, 2003; Fleming & Koppelman, 1994). From its origin as a C/SCSC this tool has developed to be what we today call Earned Value Analysis (EVA) (Anbari, 2003; Fleming & Koppelman, 1994).

EVA is a strong project management tool that integrates scope, cost and schedule under the same framework (Acebes, Pajares, Galán, & López-Paredes, 2014; Anbari, 2003). The basis of EVA is simple, a WBS, where tasks are defined, is required as input. These tasks are given cost and schedule estimates, that forms the Performance Measurement Baseline (PMB). When PMB is 100% this is the same as the initial Budget at Completion (BAC) of the project. As the project progresses, the actual work done, is compared to the PMB and the scheduled work. This gives cost and schedule variances, and the project manager can easily see whether the project is on track or not. It is not always being exactly on the PMB that counts, but to steer the project team back towards the baseline (Kuehn, 2007). EVA has generally been used to measure project performance, but can also be used to make forecast of Estimated Cost at Completion (ECAC) and Time Estimated at Completion (TEAC). Thus, provide project managers with information that, at an early stage, can help when making decisions about corrective actions or the destiny of the project (Lukas, 2008; Vargas, 2003). In larger DoD projects ECAC is used to make decisions on whether to shut down a project or not (D. S. Christensen & Templin, 2002). In a long term perspective EVA provides cost reductions of both operations and reworks (D. Christensen, 1998; Vargas, 2003).

At the expense of EVA's simplicity there are identified some limitations and weaknesses of EVA in the literature. Hall (2012) pointed out that activities are assumed to be independent, but in fact they often are dependent, and consequently variance in one task, affects the performance of another task. Thus, critical and noncritical activities are not differentiated, and this can affect the outcome of the project. As described by Sols (2015) not all tasks contribute to achieve project success, and to have full visibility of the critical tasks in the project, the relevant few are to be identified. Application of EVA also assumes a deterministic approach, that a WBS can be made before the project is initiated, this is not always the case. Such as in projects developing products with high novelty or delivering high tech products where requirements freeze is late into the project. Solomon and Young (2007) suggested in these cases that work is to be estimated in planning packages, and as the project progresses, these planning packages are updated with more detailed information. When it comes to measuring the Percent of Completeness (POC), there are no clear rules (Kuehn, 2007; Lukas, 2008; Raby, 2000). POC is often determined qualitatively, and this pollutes the analysis, as team members tend to be positive in their own sense (Hernández, Olaso, & Gómez, 2013; Lukas, 2008). The performance indexes, such as the Cost Performance index (CPI) and Schedule Performance Index (SPI($)), indicates whether a projects experiences deviations from origin plans in respectively cost or schedule. They only can say something about the past, and does not provide the project manager with information to determine whether deviations are within limits of the projects expected variability or not (Pajares & López-Paredes, 2011; Willems & Vanhoucke, 2015). Neither does the CPI or SPI($) explicitly say something about the reason for the under or over performance in cost or schedule.

In 2003, Lipke found that prediction of TEAC based on the SPI($) was unreliable, and he made an extension of EVA called Earned Schedule (ES). In brief, the method yields time-based indicators, such as SPI(t). Research has shown that ES, on an average, is a better prediction for final TEAC than other commonly used earned value-based schedule forecasting methods (Vanhoucke & Vandevoorde, 2006). The most widely used formula to find TEAC, is to take Schedule at Completion (SAC), the shortest time the project can finish, divided with the SPI($) (Anbari, 2003) or with the extension of ES, divided with SPI(t). This method of estimating TEAC assumes that extrapolations only will be applicable to the tasks on the critical path (CP), and that the CP does not change due to the new estimates (Anbari, 2003). This also gives rooms for errors in TEAC, even when making forecasts with ES.

Besides ES there has also been other extensions to EVA. One of them is Performance-Based Earned Value (PBEV), introduced and formulated by Paul J. Solomon (2005). PBEV takes, in a higher degree than EVA, into account requirements, risk and quality, and is based on standards and models for systems engineering, software engineering and project management. It is a large methodology, and does not give any parameter or metric definitions that allows it to be easily implemented.

When it comes to risk several others also have addressed this topic in combination with EVA (Acebes et al., 2014; Kim, Kang, & Hwang, 2012; Pajares & López-Paredes, 2011). Paquin, Couillard, and Ferrand (2000) introduced the earned quality method, where quality is incorporated in the analysis. To improve the prediction performance of EVA, statistical methods have been suggested integrated (Batselier & Vanhoucke, 2017; Lipke, Zwikael, Henderson, & Anbari, 2009; Narbaev & De Marco, 2014; Tseng, 2011). Other improvements have also been made to make forecasts and performance indexes more reliable. Willems and Vanhoucke (2015) found in their classification of the 187 articles and journals on project control and earned value management, that even though there have been many contributions to improve performance evaluation and forecasting techniques of EVA, only 6 of the papers categorized was about making forecasts more accurate. Chen (2014), made a new approach to increasing the prediction accuracy of the Budgeted Cost of Work Performed (BCWP) also called Earned Value (EV) and Actual Cost of Work Performed (ACWP) by further linearly modeling the PMB. Howes (2000) suggested estimates in construction projects to be assessed in work packages, this to make estimates more reliable. This works great in construction projects that by main rule are deterministic, and in addition to this, the tasks in a work package is similar to each other. On the other hand in nondeterministic projects this does not give the same accuracy, due to the nature of the work packages.

The conclusion of this would be that despite the extension of Lipke's ES and Solomon's PBEV, EVA has not been updated in a noteworthy degree since the 60's (Willems & Vanhoucke, 2015). Projects has changed over the past 50 years, and a new enhanced EVA framework is needed to make it easier for project managers to have better visibility in the project and make more accurate estimations. This to find and make the best decisions on corrective actions needed.

Enhanced Earned Value Analysis – Concept Description and Formulas

In order to develop EEVA a thorough search through literature has been conducted, and the limitations and advantages of today's way of performing EVA has been evaluated. Literature on project management has also been used to find relevant extensions to EVA. One of the main limitations and weaknesses with today's way of performing the analysis, is that it only states that there is a variance, but the visibility of where this variance stems from is not incorporated. There is also to much uncertainty in the estimates provided by EVA today. A prediction that the project will go way over budget or schedule, can in worst cases make project managers take the wrong decisions on whether to shut down a project or not. The overall goal with the EEVA is to make forecasts and predictions more accurate, by incorporating clusters, in addition to former known tools in project management. Following is a description of clusters and other project management tools incorporated in EEVA, as well as a stepwise description on how calculations and analysis are performed.

Concepts and Acronyms Relevant to EEVA

In this section concepts and acronyms relevant to EEVA will be presented. Inputs required in order to perform the EEVA are also presented in a table, where they are compared to what is required by EVA and ES, see Exhibit 1.

In a project with several tasks of different nature, it can be difficult to see the full picture and know the reasons for the variances. In EVA today, forecasts on future performance in the project, derives from an assumption that variances in one task can be extrapolated to all other tasks in the project. As described by Howes (2000) this way of making predictions make estimates less accurate and less reliable. E.g. if there is a cost variance in a task related to project management, EVA makes extrapolations of this to all other tasks in the project. This would probably not affect neither development or production related tasks. This is a problem with today's way of making forecasts with EVA and the reason why clusters are incorporated to EEVA.

Clusters: Clusters are a set of tasks. The tasks are divided into clusters by their nature, in this case meaning that the tasks in the cluster share a common denominator. Among others, it can be that the tasks are performed by the same group of people, or that performance of the task relies on the same process. The idea behind this is that if a variance occurs in a task, this information is used as input to make new predictions of what other tasks, that share a common resource may demand. This justifies extrapolations made, and make estimates more reliable, and is also one of the major advantages with the clusters. Thus, when a task in a cluster suffers from variances, these variances are only extrapolated to the other tasks in the same cluster. The clusters increase the visibility of variances. They also make it easier for the project manager to see patterns, thus helping in when taking decisions in the project.

To not complicate the EEVA framework, tasks can for now, only belong to one cluster at a time. In cases where at task ideally should have belonged to two clusters or more, a decision of the most suitable cluster for the task needs to be done. It is up to the project manager to decide which tasks should be in the same cluster. How calculations in the cluster are carried out, is described later in this paper.

Inputs relevant to EEVA. Inputs relevant to EEVA are now presented. Like in EVA, the Work Breakdown Structure (WBS) is essential to define the work of the project, and divide it into tasks. As earlier addressed, this can

be difficult in non-deterministic projects, and when not possible to assess all tasks before project is initiated it is suggested to make planning packages. As the project progresses, these planning packages are updated with more detailed information.
Task and planning packages identified by the WBS are given cost and time estimates. The estimates should desirably be as realistic as possible, and different software tools and techniques exists to get these estimates as accurate as possible. The input required to EEVA is the Estimated Cost (EC), Estimated Duration (ED), as well as the estimated start and finish of the task. The total sum of all EC is the initial Budget at Completion (BAC), i.e. this is the total estimated cost of the project before it is initiated. Schedule at Completion (SAC) represents the shortest possible time the project can finish, and is found with help of the Critical Path Method (CPM). For tasks that is not a part of the Critical Path (CP), Slack Time (ST) can be identified. Slack Time, also called float, is the amount of time that a task in a project can be delayed without causing a delay to subsequent tasks or to the project completion date (PMI, 2013).

To reflect the uncertainty of the project, estimates of both optimistic and pessimistic cost and duration with associated early and late start and finish of a task is to be given. Respectively called EC_O, ED_O, EC_P and ED_P, desirable this should be reflected in all tasks, but it can be challenging to do so. Therefore, it is suggested that only the relevant few are given optimistic and pessimistic estimates. As described by Sols (2015), in a project there are a few key tasks that needs to be watched closely to lessen the project's likelihood to derail, so that project success can be achieved. These tasks are called the relevant few and to determine these tasks project managers needs to identify tasks in five key areas, time, skills, performance, cost and external dependencies.

Exhibit 1. Overview of Input Required by EVA/ES compared to EEVA.

Acronyms	Description	EVA / ES	EEVA
CL	Cluster, tasks are clustered if they share a common denominator		X
CP	Critical Path, is the task a part of the critical path or not I/0		X
EC	Estimated Cost per task	X	X
EC_O, EC_P	Estimated cost per task optimistic, pessimistic		X
ED	Estimated Duration per task	X	X
ED_O, ED_P	Estimated Duration per task optimistic and pessimistic		X
RF	Relevant Few		X
ST	Slack Time per task		X
	Estimated start and finish of a task	X	X
WBS	Work Breakdown Structure	X	X

Performance of EEVA

In this section, a stepwise description of the performance of EEVA is presented, the steps are also illustrated in a flowchart see Exhibit 2. Most of the steps involves formulas and these are also summarized in a table together with a list of the acronyms, see Exhibit 3. Before the steps are described some definitions needs to be addressed.

Regarding task time and project duration following definitions are used. Increase or reduction in a tasks duration, is when the Actual Duration (AD) of a task is longer or shorter than estimated. Late or early start of a task is when a task starts later or earlier than expected due to task duration in previous tasks or other conditions. Project delay or acceleration is when a project is behind or ahead of schedule, due to respectively increase or reduction in task duration, or late or early start of a task.

A variance in EEVA is when there are deviations in the actual compared to the initial cost or schedule estimates. If a variance is < 0 this means that the project is suffering from a cost overrun or delay. The performance index tells whether the project performs better or worse than expected. A performance index >1 means the project is doing better than estimated and vice versa.

The outputs of the coming steps are used in the analysis of the project, step 1 is the first to be presented.

Step 1. Outputs from this step will be used as input to calculations in some of the following steps. Following outputs is desirable to find: the initial BAC and SAC of the project. To reflect the uncertainty of the project an optimistic and pessimistic BAC and SAC, which is respectively called BAC_O, SAC_O, BAC_P and SAC_P. It is also required to find the BAC and the SAC for the clusters, called BAC_{CL} and SAC_{CL}. As cost and schedule calculations will be different from each other they will be presented individually, starting with the cost.

Inputs required to do calculations in order to find the cost related outputs are: EC, and EC_O as well as EC_P for tasks that is a part of the relevant few.

$BAC = \Sigma EC$

$BAC_O = \Sigma EC + \Sigma EC_O$ for tasks ∈ relevant few

$BAC_P = \Sigma EC + \Sigma EC_P$ for tasks ∈ relevant few

$BAC_{CL} = \Sigma EC_{T\in CL}$

CPM is used to find SAC, as well as SAC_O and SAC_P which represents the shortest possible time the project can finish in. Inputs required to use the CPM is the ED, and ED_O as well as ED_P for tasks that is a part of the relevant few. In addition to this the estimated start and finish for the tasks. When it comes to SAC_{CL} this is calculated separated from time. I.e. all tasks durations are added up regardless of whether they can be performed at the same time or not. SAC_{CL} is found by the total sum of the tasks durations, given with the following formula:

$SAC_{CL} = \Sigma ED_{T\in CL}$

Step 2. After the project has been initiated, all tasks are to be assessed, if not possible to do all, at least the relevant few. The outputs from this step is the Actual Cost of Work Performed per task ($ACWP_T$), Actual Duration per task (AD_T) and POC per task (POC_T) or the Remaining Percent to Complete per task (RPTC). These outputs will be used in calculations in the next steps of the analysis.

Step 2.1 is to find the $ACWP_T$, this is found by looking at the actual costs incurred per task.
Step 2.2. here AD_T needs to be determined, this is the actual time incurred from the task was started until the measurement point.
Step 2.3 is to find the POC_T and the RPTC. As already addressed the best way of determining POC_T is objectively, but if this is not possible, a subjective estimate is better than no estimate. When no other option than to make a subjective assessment, it is suggested to ask how much is left, rather than how much is progressed. The reason for this, is that project team members often are more optimistic when it comes to what they have achieved, than what is left. RPTC reflects the remaining percentage to complete. The sum of POC_T and RPTC for a task will always be 100%. Thus, if the POC_T is 75% the RPTC is 25%. Tasks are by main rule assumed to follow a linear workload and progression. In cases where cost or work effort is assumed to be concentrated in the beginning or end of the task, earning rules are to be determined up front. This to avoid false variances which pollutes the analysis. E.g. in cases where cost and effort is expected concentrated at the end of the task, the POC_T of this task should be either 0% or 100%. Thus, the earning rule for this task would be 0%/100%.

Step 3. This step provides project manager with information about the cost performance of a cluster, and can be used to make extrapolations to the other tasks in the same cluster. The outputs from step 3 will also be included when doing calculations of cost and performing the analysis of the entire project. How the results can be construed will be further described in step 7. Following outputs are required from a cluster, $ACWP_{CL}$, $BCWP_{CL}$, CPI_{CL}, CV_{CL}. To be able to calculate the ECAC for the entire project, the New Estimated Cost per Task (NECT) also needs to be found. The inputs required to do these calculations are the EC, $ACWP_T$, POC_T, and the RPTC. The formulas required for the outputs are now presented in steps.

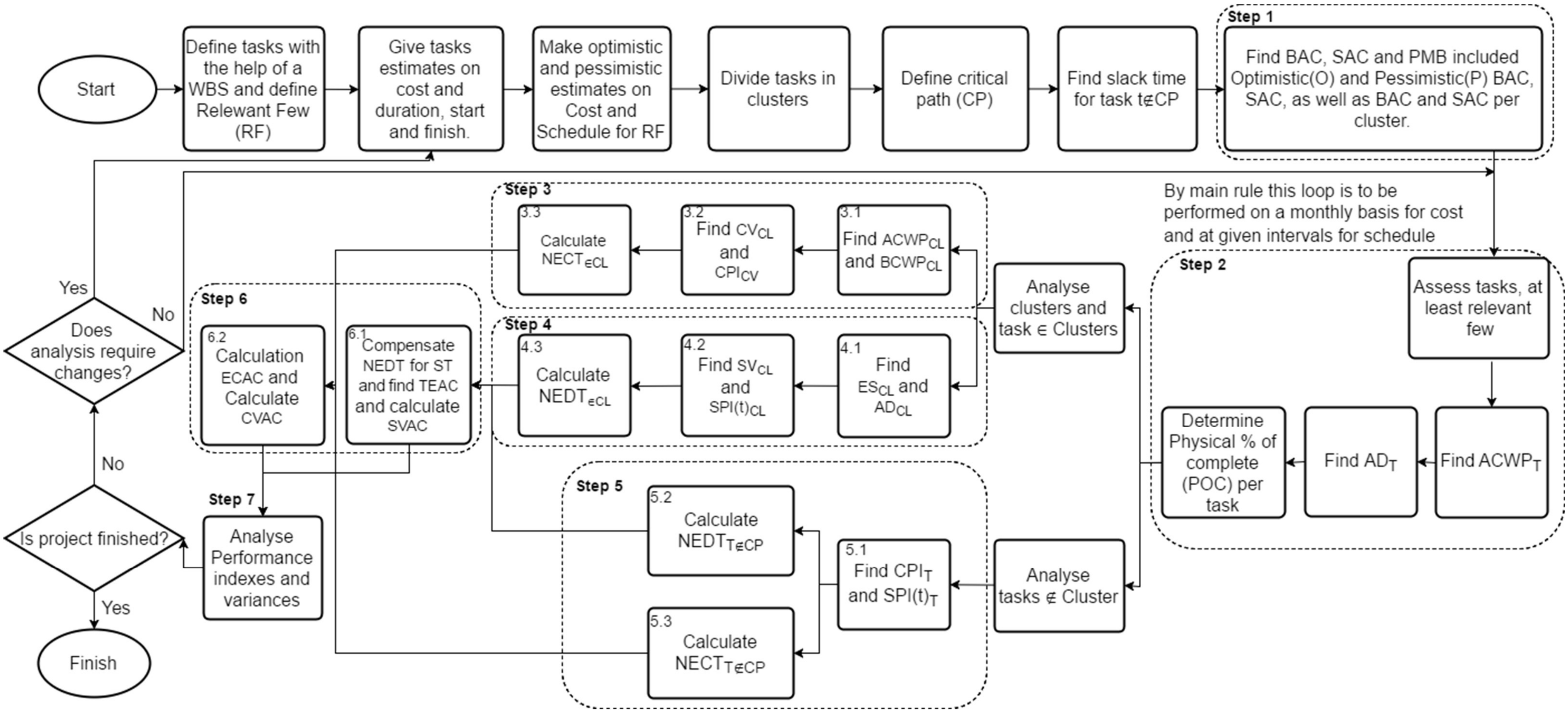
Step 3.1. Find $ACWP_{CL}$ and $BCWP_{CL}$: $ACWP_{CL} = \Sigma ACWP_{T\in CL}$ and $BCWP_{CL} = \Sigma\ (EC_{T\in CL} * POC_{T\in CL})$

Step 3.2. Find CV_{CL} and CPI_{CL}: $CV_{CL} = BCWP_{CL} - ACWP_{CL}$ and $CPI_{CL} = BCWP_{CL} / ACWP_{CL}$

Step 3.3. Find $NECT_{\in CL}$: $NECT_{\in CL} = ACWP_T + ((EC_{T\in CL} * RPTC) / CPI_{CL}))$

The formula of $NECT_{\in CL}$ is to be used whether the task is initiated or not, also if the task is finished, this because it is easier to just have one formula to manage. I.e. if a task is not initiated yet, this means that RPTC = 100% and that $ACWP_T$ is 0. In the opposite case if a task is finished, this means that RPTC = 0%, and NECT = $ACWP_T$ + 0. The advantage of the NECT formula is that extrapolations only are made to the remaining work of the task, in contrast to EVA where extrapolations also are applied to tasks already finished. This also applies to NEDT, that will be described in step 4.

Exhibit 2. Flowchart of EEVA



Step 4. This step provides project manager with information about the schedule performance of a cluster, and in the same way as the cost is analyzed, this can be used to make extrapolations to the other tasks in the same cluster. The outputs from this step will be included when doing calculations of schedule and performing the analysis of the entire project. Following outputs are required from a cluster, AD_{CL}, ES_{CL}, SV_{CL} and the $SPI(t)_{CL}$. To be able to find TECAC for the entire project, the New Estimated Duration per Task (NEDT) also needs to be found. It is important to notice that for now, only the duration of the task is assessed, and not if the task has an early or late start. How NEDT is compensated for CP and ST and early or late start, is further described in step 6.1. The inputs required to do the calculations of step 4 are the AD_T, ED, POC_T, and the RPTC. The formulas required for the outputs are now presented in steps.

Step 4.1. Find AD_{CL} and ES_{CL}: $AD_{CL} = \Sigma ACWP_T$ and $ES_{CL} = \Sigma(ED_{T\in CL} * POC_{T\in CL})$

Step 4.2. Find SV_{CL} and $SPI(t)_{CL}$: $SV_{CL} = ES_{CL} - AD_{CL}$ and $SPI(t)_{CL} = ES_{CL} / AD_{CL}$

Step 4.3. Find $NEDT_{\in CL}$: $NEDT_{\in CL} = AD_T + ((ED_{T\in CL} * RPTC) / SPI(t)_{CL}))$

Step 5. The output of this step is the CPI and SPI(t) per task (CPI_T, $SPI(t)_T$), $NECT_{\notin CL}$ and $NEDT_{\notin CL.}$ As shown in step 6, $NECT_{\notin CL}$ and $NEDT_{\notin CL}$ are needed to find the total ECAC and TEAC of the project. For the relevant few in particular the CPI_T and the $SPI(t)_T$ are especially interesting to know. Calculations in this step, is only applied to the tasks that is not a part of a cluster, and only applicable to the tasks that are already initiated. The idea is to make extrapolations to the remaining work of the task, based on the variances earlier in the task. The input needed to do the calculations are, $ACWP_T$, AD_T EC, ED, POC_T and the RPTC of the task. The formulas are now presented in the order they are to be carried out.

Step 5.1 Find CPI_T and $SPI(t)_T$. $CPI_T = (EC*POC_T)/ACWP_T$ and $SPI(t)_T = (ED*POC_T)/AD_T$.

Step 5.2 Calculate $NEDT_{\notin CL.}$ $NEDT_{\notin CL} = AD + ((ED * RPTC)/SPI(t)_T)$

Step 5.3 Calculate $NECT_{\notin CL.}$ $NECT_{\notin CL} = ACWP_T + ((EC * RPTC)/CPI_T)$

How NEDT is compensated for CP and ST is further described in step 6.1.

Step 6. This step is divided in 6.1 and 6.2 whereas the former gives output on time estimates and the latter on cost estimates. The outputs from step 6 provide project managers with information on whether the project is expected to suffer from a cost or schedule overrun or not, when it reaches its finish date. The outputs needed to do so, are the TEAC, ECAC and belonging variances at completion, SVAC and CVAC. How calculations are to be performed and what input is required will be described separately for schedule and cost in 6.1 and 6.2.

Step 6.1. As earlier addressed, in this step TEAC and Schedule Variance at Completion (SVAC) is to be found. One of the inputs to calculate the latter is TEAC and that is why they are explained separately. Starting with TEAC.

The TEAC of the project provides project managers with information on whether it is assumed that the project will deliver on time or not. To know whether the TEAC is higher than the initial SAC, hence in when decisions on actions to be taken are made. Input required to find the TEAC is the ST of the path the task is in, NEDT and ED for the tasks ∉ cluster ($ED_{T\notin CL}$). To find out if NEDT can be absorbed by the ST, it is important that the calculations are carried out in the order that the tasks are estimated to start. Starting with the once already initiated, and the ones in the nearest future. If NEDT of a task cannot be absorbed by ST, this leads to a late start of subsequent tasks, thus the ST for the upcoming tasks needs to be updated. To find whether the NEDT can be absorbed by the ST or not, following rules can be used.

Scenario 1: If NEDT < (ED + ST) - no actions needed.

Scenario 2: If NEDT > (ED +ST) – estimated start date and ST of subsequent tasks needs to be updated.

Changes in one of the paths may also alter the CP. If there is an increase in task duration in the CP, or if scenario 2 occurs, then TEAC needs to be updated. The easiest way to do this is by using CPM with the NEDT, the $ED_{T\notin CL}$, and the new estimated start and finish for the tasks. In complex projects with many tasks and long duration, it can be challenging to keep the dataset updated and in these cases, it is suggested that this is not performed as often as for the calculations of ECAC.

If an estimated SVAC occurs, this means that the project is likely to have a deviation from the initial SAC at the finish date of the project. If this is the case it is interesting to know whether this variance is within the limits given by the uncertainty of the project. The input required to find these variances is TEAC, the initial SAC as well as SAC_O SAC_P. First the SVAC is calculated, and if this equals 0, then no further calculations need to be done. On the other hand, if there is a variance, it is important to know whether this variance is within the limits of the initial SAC_O and SAC_P. When comparing TECAC with SAC_O and SAC_P the variance is respectively called $SVAC_O$ and $SVAC_P$. The formulas for SVAC are now presented.

$$SVAC = TECAC - SAC$$

$$SVAC_O = TECAC - SAC_O$$

$$SVAC_P = TECAC – SAC$$

Step 6.2 In this step ECAC and the belonging estimated Cost Variance at Completion (CVAC) is to be found. These outputs provide project managers with information on the estimated cost at the end of the project. Compared to the initial BAC of the project it gives the estimated Cost Variance at Completion (CVAC). Since ECAC is needed to calculate the CVAC, the will be presented in separate sections, starting with the ECAC.

The inputs required to calculate ECAC is the $NECT_{\in CL}$, $NECT_{\notin CL}$ and EC for tasks that is not a part of a cluster and not yet performed ($EC_{\notin CL=0\%}$). The formula of how this is calculated is now presented.

$$ECAC = \Sigma NECT_{\in CL} + \Sigma NECT_{\notin CL} + \Sigma EC_{\notin CL=0\%}$$

The estimated Cost Variance at Completion (CVAC) tells if the project is likely to have a cost overrun or not, and if the variance is within the limits set by the uncertainty of the project. The input required to find the variances at completion is ECAC, the initial BAC as well as BAC_O BAC_P. First the CVAC is calculated, and if this is equals to 0 then no further calculations need to be done, but if there is a variance it is important to know whether the variance is within the limits of the initial BAC_O and BAC_P. When comparing ECAC with BAC_O and BAC_P the variance is respectively called $CVAC_O$ and $CVAC_P$. The formulas for CVAC are now presented.

$$CVAC = ECAC - BAC$$

$$CVAC_O = ECAC - BAC_O$$

$$CVAC_P = ECAC - BAC_P$$

Step 7. In this step an introduction, on how the results can be analyzed, is given. The analysis of the results can be done in three levels. Project level, cluster level, and task level, for the latter the analysis is only applied to the relevant few. The output from the previous steps is used as input to the analysis, and the following inputs are interesting for project managers to take into consideration.

Project level: CVAC, $CVAC_O$, $CVAC_P$, SVAC, $SVAC_O$ and $SVAC_P$

Cluster level: CPI_{CL}, CV_{CL}, $SPI(t)_{CL}$ and $SV(t)_{CL}$

Task level, the relevant few: NECT and NEDT.

If the project is predicted to have an estimated CVAC or SVAC this should be a concern for the project manager, and the reason for the estimated variance should be investigated. It is assumed that cost or schedule overrun is worse than the opposite, but if a positive variance is found compared to BAC_O or SAC_O ($CVAC_O$ or $SVAC_O$) the project manager should still be on guard, and ask control questions. Is quality as expected, is cost vs schedule as expected, or is the cost of the project below budget, but it suffers from delays or vice versa. If a project experiences estimated variances at completion and the project manager wants to find the reason, this can be done by first looking at the clusters.

A CPI_{CL} or $SPI(t)_{CL} \neq 1$ indicates that the cluster is doing better or worse than expected. These indexes only say something about the past, but when variances occur, the reason for this should be investigated. Clusters will also increase visibility of patterns, and the reasons of the variance are easier to determine. If action is needed it is easier to prioritize where resources needs to be used. If CPI_{CL} and $SPI(t)_{CL} = 1$ and the project experiences variances, this indicates that the tasks $\notin$ cluster are the main reason for the variance, and the reason for this need to be established. On task level the relevant few can be assessed by looking at the NECT and NEDT compared with respectively EC_O, EC_P and ED_O ED_P. This way of analyzing the results gives project managers the holistic view, but allows them not to be caught up in details.

Exhibit 3. Summary of Acronyms and Formulas Used in EEVA

Acronyms	Description	EEVA formulas
$ACWP_{CL}$	Actual Cost of Work Performed per Cluster	
$ACWP_T$	Actual cost of Work Performed per Task	
AD_T	Actual Duration per Task	
AD_{CL}	Actual Duration per cluster	The total sum of AD_T of all tasks included in a cluster.
BAC	Budget at Completion	ΣEC The initiated total estimated cost of the project
BAC_{CL}	Budget at Completion per Cluster	The total estimated cost per cluster
BCWP	Budgeted Cost of Work Performed	BAC * POC
$BCWP_{CL}$	Budgeted cost of Work Performed per Cluster	$\Sigma(EC_{T\in CL} * POC_{T\in CL})$
CV_{CL}	Cost Variance per Cluster	$BCWP_{CL} - ACWP_{CL}$
CV_T	Cost Variance per Task	$(EC * POC_T) - ACWP_T$
CP	Critical Path	
CPI_T	Cost Performance per Task	$(EC * POC_T)/ACWP_T$
CPI	Cost Performance Index	
CPI_{CL}	Cost Performance Index per Cluster	$BCWP_{CL}/ACWP_{CL}$
CVAC	estimated Cost Variance at Completion	ECAC – BAC
ECAC	Estimated Cost at Completion	$\Sigma NECT_{\in CL} + \Sigma NECT_{\notin CL} + \Sigma EC_{\notin CL=0\%}$
EC	Estimated Cost per task	Initial estimated cost per task
EC_O, EC_P	Estimated cost per task optimistic, pessimistic	
ED	Estimated Duration per task	
ED_O, ED_P	Estimated Duration per task, optimistic and pessimistic	
EVA	Earned Value Analysis	
ES_{CL}	Earned Schedule per Cluster	$\Sigma(ED_{T\in CL} * POC_{T\in CL})$
$NECT_{\in CL}$	New Estimated Cost per Task ∈CL	$ACWP_T + ((EC * RPTC_T)/CPI_{CL})$
$NECT_{\notin CL}$	New Estimated Cost per Task ∉CL	$ACWP_T + ((EC * RPTC)/CPI_T)$
$NEDT_{\in CL}$	New Estimated Duration per Task ∈CL	$AD + ((ED * RPTC_T)/SPI(t)_{CL})$
$NEDT_{\notin CL}$	New Estimated Duration per Task ∉CL	$AD + ((ED * RPTC)/SPI(t)_T)$
POC	Percent of Completeness project	
POC_T	Percent of Completeness per task	
RPTC	Remaining Percent to Complete per task	$100\% - POC_T$
$SPI(t)_T$	Schedule Performance Index (time based) per task	$(ED*POC_T) / AD_T$
$SPI(t)_{CL}$	Schedule Performance Index (time based) per cluster	ES_{CL} / AD_{CL}
$SV(t)_{CL}$	Schedule Variance (time based) per cluster	$ES_{CL} - AD_{CL}$
$SV(t)_T$	Schedule Variance (time based) per task	$(ED * POC_T) – AD_T$
SVAC(t)	Estimated Schedule Variance at Completion (time based)	TEAC(t) – SAC
SAC	Schedule at Completion (the shortest time the project can finish in)	
ST	Slack Time	
TEAC(t)	Time Estimated at Completion (time based)	Using CPM with $NEDT_{\in CL}$, $NEDT_{\notin CL}$, $ED_{\notin CL=0\%}$

Case Study (Appendix I)

The EEVA model was implemented to a test project to validate the model. Due to the confidentiality aspect of this project this is described in Appendix I

Implications for Engineering Managers

In this paper, a full description of the EEVA framework with flowchart and formulas has been presented. It has been given as a stepwise description, that will function almost like a recipe. The ingrediencies needed to do the calculations are described and presented in the tables of this paper. There are several implications why EEVA should be used in project planning and execution. First of all, engineering managers will benefit from having a more reliable method for updating their project plan, and can use gathered data to aggregate new estimates. Second, they will have higher visibility in the actual link between registered deviations and the remaining parts of the project. This visibility will also make it easier to see patterns, this will hence in when trying to determine where to start looking for the root causes of the deviations. Third, it will provide engineering managers with the ability to have a holistic view, but at the same time know enough about the details of the project to take the right decisions. Fourth, when deviations to the initial plan occurs, engineering managers will have the ability to know whether these deviations are within the limits set by the uncertainty of the project or not. This can save time and effort, stopping managers to search for the root causes to deviations that most likely was to occur anyway.

Conclusion

EEVA has been developed based on a thorough search through literature. In this paper, a complete method on how to conduct EEVA has been presented. At time being EEVA is tested on a pilot project. For the reason of SEMP timescales and the time taken to get clearance to gain access to the classified data in the selected project, only a preliminary validation has been achieved. Due to the nature of the pilot project some features of EEVA cannot be expected to be fully validated. To gain proper validation of schedule estimates it would be desirable to implement EEVA to a project with a higher visibility of the Critical Path.

As for now tasks can only belong to one cluster without complicating the calculations, suggestions for further research is to find a solution where tasks can be in several clusters at the same time.

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