INTRODUCTION TO EARNED DURATION

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ABSTRACT

The management of project baseline schedules has evolved significantly since the development of the Gantt chart in the early 20th century (Gantt, 1919). In the next few decennia, the Program Evaluation and Review Technique/Critical Path Method and the Precedence Diagram Method (Fondahl, 1987), and more recently, the Critical Chain Project Management technique (Goldratt, 2002) saw the light.

The evolution of microcomputers and their software simplified the usage of these techniques in project management. Furthermore, the concept of "earned value" emerged early in the 20th century and was largely based on the principle of "earned time", which was popularized by Frank and Lillian Gilbreth (Solanki, 2009). In the 1960s, the Department of Defense of the US government used it to create the PERT/COST technique (Hamilton, 1964), which later evolved into the Cost/Schedule Control System Criteria or C/SCSC (Christensen, 1990). In the late 1970s, the latter technique culminated in the Earned Value Management (EVM) method (Fleming & Koppelman, 2010). EVM rose to prominence in 1991 when the US Navy Avenger II program was canceled because of performance issues in its cost/schedule objectives that had been detected by EVM (Stevenson, 2001).

EVM, as a project management methodology, achieved enormous success on cost management, but almost none in schedule management. This was due to the idiosyncrasies of its schedule indicators, as they fail in the final portion of the schedule for late projects (see Figure 3), which generated disbelief in EVM's applicability for schedule management. Therefore, EVM has been used almost exclusively for cost management for many years. However, the Earned Schedule (ES) technique, created in 2003 by Walt Lipke (Lipke, Schedule is Different, 2003), changed the way of computing schedule indicators in order to eliminate their shortcomings. In academic studies by Vanhoucke (2010; 2011; 2014), it has been shown that the ES method outperforms the traditional methods of EVM. However, although the new indicators indeed perform better, the use of cost data in their calculation causes the obtained information to not always be reliable. Therefore, prof. dr. Homayoun Khamooshi and Hamed Golafshani recently published a paper describing a new approach for project schedule performance management (Khamooshi & Golafshani, 2014). The new technique, Earned Duration Management (EDM), eliminates the use of cost data in the schedule context.

THE EVM S-CURVE AND ITS USE IN ES

Before proceeding to the conceptualization and application of the new EDM approach, a review of the foundations supporting its introduction is provided. More concretely, the EVM S-curve and its use in ES are described.

S-CURVE CONCEPT

Consider a project A that aims at building up a wall of 2000 bricks, planned to last 10 days, and performed by a bricklayer who works on average four hours a day. This project is represented by just one activity that extends from day 1 to day 10. Suppose that the bricklayer costs $20 per hour, which results in a project budget of $800. Under these conditions, the bricklayer must lay 200 bricks per day and has to be paid $80 daily. Table 1 summarizes the planned evolution of project A's cost during the 10-day lifetime.

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Time Days)	1	2	3	4	5	6	7	8	9	10
Planned Value	$80	$160	$240	$320	$400	$480	$560	$640	$720	$800

Table 1: Evolution of planned costs for project A

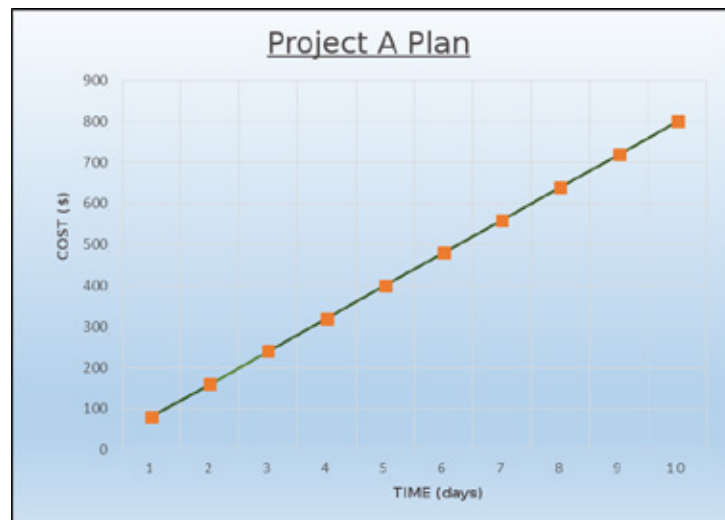Furthermore, the chart in Figure 1 visualizes the table values.

Figure 1: Evolution of planned costs for project A

The displayed curve, which is a straight line in our simple example, is known in project management jargon as the "S-curve" (Dinsmore & Silveira Neto, 2004). It is a graph that traditionally displays the relationship between two variables, namely time and cost (or effort in some cases). For larger projects, the same construction process would yield a curve with a small inclination at the beginning (i.e. allocation of personnel and materials are still rather limited at the start of the project), an increasing slope during the middle periods where there is greater activity and generally a higher rate of cost growth, and again a smaller rise in its final phase reflecting the decreasing rate of effort and spending (i.e. only a few closing activities remain at the end of the project). In our example, the agreement with the bricklayer was that he would be paid based on the number of hours that he dedicated to the project. Assume that the project has started and is now at its fifth day. The records of the hypothetical progress monitoring are shown in Table 2.

Time (Days)	1	2	3	4	5	6	7	8	9	10
Planned Value	$80	$160	$240	$320	$400	$480	$560	$640	$720	$800
Actual Cost	$80	$184	$296	$392	$536					
Earned Value	$80	$120	$160	$224	$256					

Table 2: Actual progress of project A at day 5

It can be seen that the actual cost (AC) was equal to the planned value (PV) only at the end of the first day of project execution. Over the next four days, there was an occurrence of bad weather, delays in delivery, and mistakes in the number of delivered bricks. This forced the bricklayer to dedicate an unforeseen amount of hours on actions different from the plan, every day of the project. For this reason, the AC was always higher than the PV. However, the monetary value of the progress made (work completed) at a certain point in time, known as the Earned Value (EV), remained below the PV.

The measurement of work performed (i.e. EV) at a certain day was based on the number of bricks laid that day multiplied by the cost per brick of $0.40 ($80/200). The $120 value on the second day reflects that, by the end of this day, project execution achieved only half of what was planned for that day. On the third day, the execution kept running late in relation to what was planned, and instead of having fulfilled the PV of $240, the EV was just $160, which had been planned for the end of the second day. At the end of the fifth day, the EV ($256) was only slightly higher than the PV for day 3.

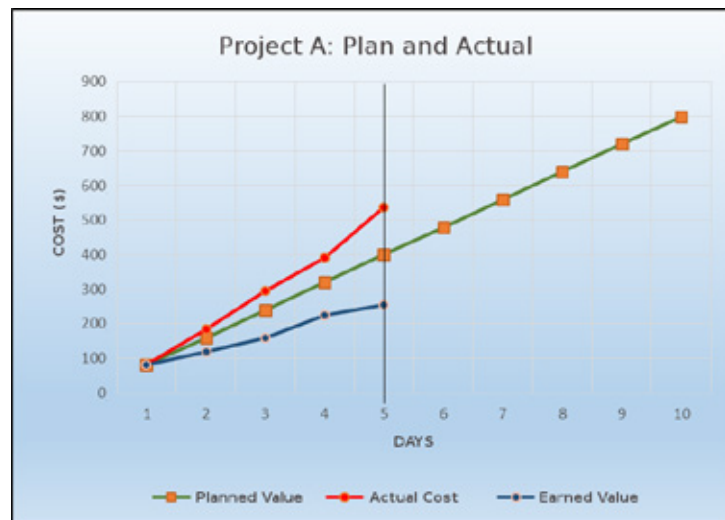The graph of Figure 2 corresponds to the values of Table 2.

Figure 2: Actual progress of project A at day 5

The vertical line on the fifth day indicates the time that the project manager delivered his status report. The green line represents the PV, which is the same as shown in Figure 1. The red line corresponds to the AC accumulated at the end of each period (i.e. each day). The blue line is the result of project progress measurement, which is expressed in terms of the value actually earned (i.e. EV) at a certain point in time. One may notice that at the end of day 5, the project cost exceeded the value that was planned at this point, whereas the progress measured was lower than planned. Through this simple example, we have introduced the basis of what is known as EVM in project management.

Furthermore, the fifth period in the example, at which the current measurement was made, is referred to as the Actual Time (AT) and represents the elapsed time from the beginning of the project. Summarizing the other key metrics, the cumulative budgeted value at the end of a period is identified as the PV of that period. In the case above, the PV is $400 by the end of the fifth period. The EV, corresponding to what was actually accomplished by the end of day 5, is $256. The AC accrued by the end of the fifth period is $536. Furthermore, the total amount budgeted for project A, $800, is called Budget at Completion (BAC).

The EVM key metrics can also be used to obtain measures of project performance. For example, the difference between EV and AC at a specific point of measurement is known as the Cost Variance (CV). The difference between EV and PV receives the name of Schedule Variance (SV). However, while the SV indicates duration, its measurement unit is expressed in monetary terms. This has been the subject of many EVM criticisms in the project management community. Furthermore, the ratio of EV to AC is the Cost Performance Index (CPI) and the quotient of EV to PV is the Schedule Performance Index (SPI). Summarizing, the EVM performance measures are:

- Cost Variance: $CV = EV - AC$
- Schedule Variance: $SV = EV - PV$
- Cost Performance Index: $CPI = EV/AC$
- Schedule Performance Index: $SPI = EV/PV$

It is well known that the EVM schedule indicators are flawed. This statement is easily demonstrated by the analysis of the SPI behavior at the end of a late project. At that point, the EV reaches its maximum value of BAC, and consequently, the SPI becomes 1, indicating that the project ended right on time. Figure 3 graphically illustrates this aberration in EVM behavior. Consequently, the EVM schedule indicators always inform the project manager that the project ended at its planned time, even if the project is completed with a delay. Lipke (2009) stated that the anomalous behavior of the EVM schedule performance indicators starts when the project reaches 65% of its completion. These results have also been obtained in simulation studies performed by Vandevoorde and Vanhoucke (2006), Vanhoucke and Vandevoorde (2007) and Vanhoucke (2010).
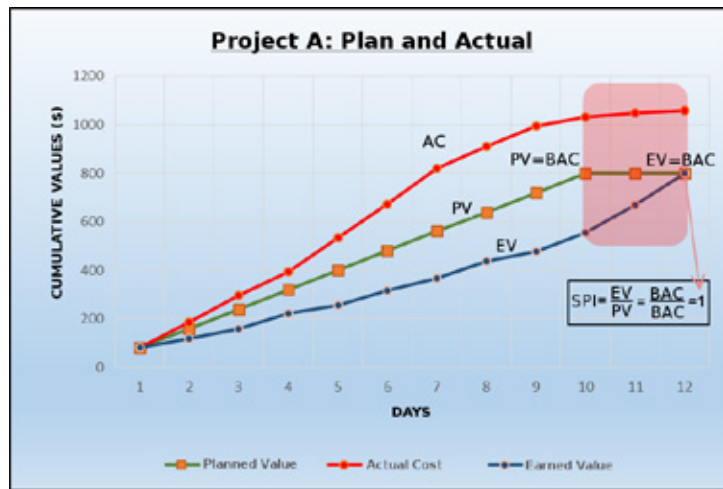
Figure 3: Calculation of SPI near the project end

EARNED SCHEDULE CONCEPT

The anomalous behavior of the EVM schedule indicators provided the motivation for the development of the Earned Schedule (ES) concept by Walt Lipke (2003; 2009). The basic idea is that project schedule management techniques should be able to evaluate schedule performance in units of time (Figure 5), and not in monetary terms as in the EVM methodology (Figure 4).
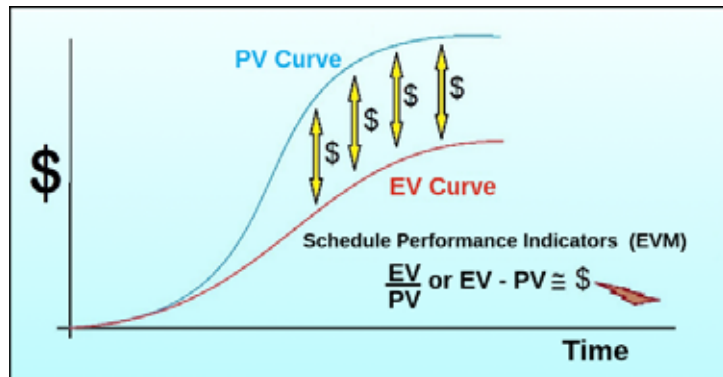

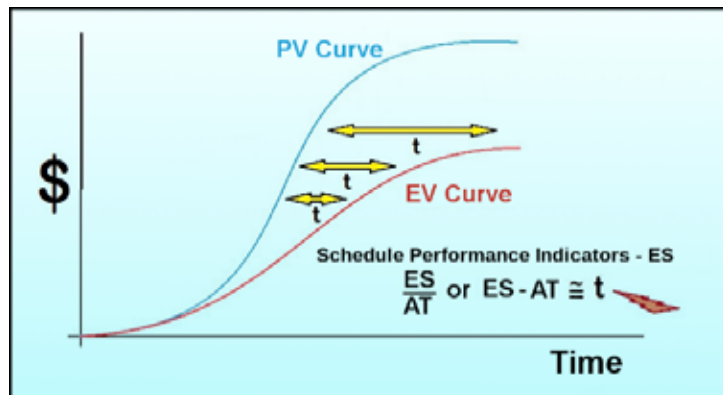Figure 4: Basic principles of schedule performance measurement with EVM

Figure 5: Basic principles of schedule performance measurement with ES

Lipke's ES technique provides a solution to this problem and resolves the existing inconsistencies for SPI and SV. The ES value can be graphically determined by finding the point where the horizontal projection of the EV at a given time meets the PV curve. The projection of this point on the time axis (horizontal coordinate) then defines the ES. This procedure is visualized in Figure 6.
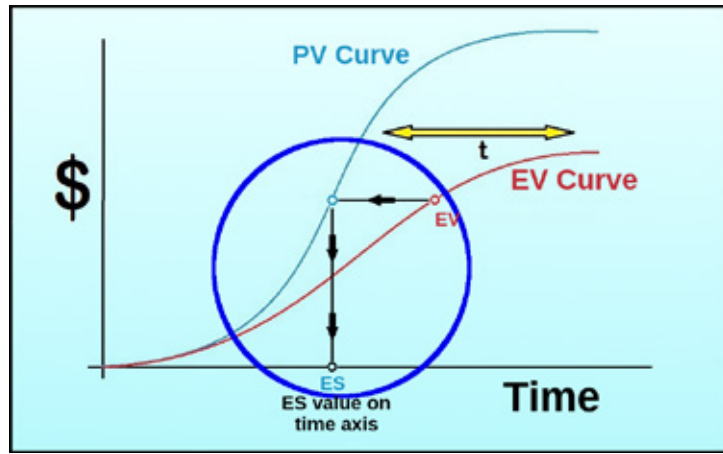
Figure 6: Basic principles of ES calculation

In order to explain the process of calculating the numerical value of ES, we zoom in on the area within the blue circle in Figure 6 and thus produce Figure 7. Note that this zoom is conceptual and should therefore not be regarded as an exact representation of the situation in Figure 6. As the point found on the PV curve can reflect any time instant, one must select the integer time value immediately to the left of the projection of the point on the horizontal axis and then calculate the fraction of time to be added to the integer in order to obtain the ES value.

The algebraic calculation of ES is based on the similarity of triangles from basic geometry (see upper right corner of Figure 7). We now refer to Figure 7. First, we define the range $[t, t + 1)$ as the consecutive integer times between which the projection of the PV curve point on the horizontal axis is situated. The range of PVs $[PV_t, PV_{t+1})$ that contains the projection of the EV on the vertical cost axis forms the vertical side $(PV_{t+1} - PV_t)$ of the larger triangle and is called "B". The difference between the EV and the PV at time t defines the vertical side of the smaller triangle and is referred to as "b". The horizontal side of the bigger triangle is equal to 1 UC (Unit of Calendar) because $(t + 1) - t = 1(UC)$ and is called "A". The difference in time between the value of ES and the time t is the horizontal side of the smaller triangle and is indicated by "a". Since the distance "d" (in time units) between the point actually found on the PV curve and the point on the larger triangle hypotenuse is much smaller than the value of ES to be calculated ($d << ES$) it can be stated that:

$$\left(\frac{a}{A} = \frac{b}{B} \right) = \left(\frac{ES - t}{(t + 1) - t} = \frac{EV - PV_t}{PV_{t+1} - PV_t} \right)$$
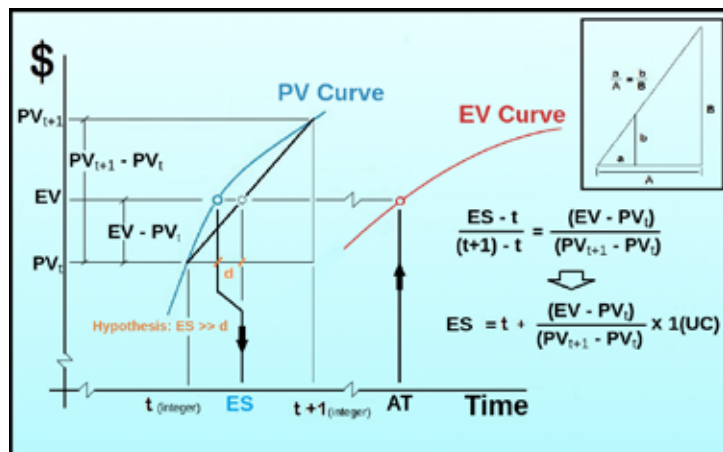

Figure 7: Detailed ES calculation

From the above equation, the formula for calculating ES can be derived:

$$ES = t + \frac{EV - PV_t}{PV_{t+1} - PV_t} \times 1(UC)$$

Here, t is the largest integer time period that is smaller than ES. The *t* and *t+1* subscripts for PV indicate that it concerns the PV values at those particular time periods. The factor *x 1(UC)* accomplishes the conversion of the dimensionless fraction to time units. Figure 8 shows the application of the ES calculation for project A at the fifth day.
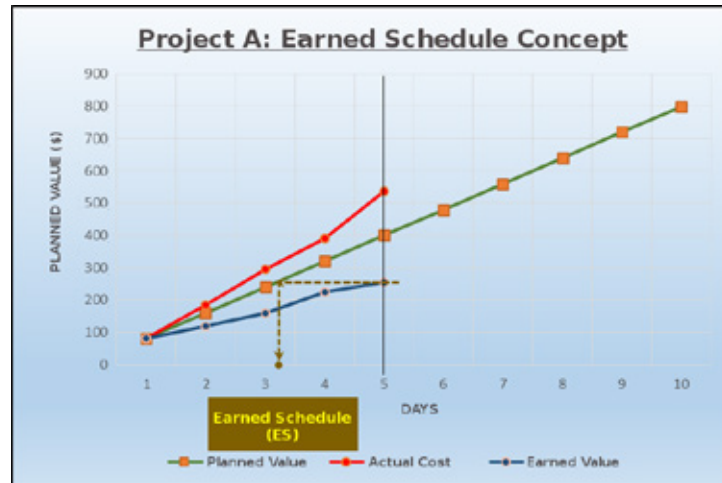

Figure 8: ES calculation for project A at day 5

From the graph in Figure 8, one can observe that after five elapsed days from the start of the project, the ES is just a little over three days. In other words, the project is nearly two days late. On the other hand, EVM informs us that the project, on its fifth day, is late by $144 (i.e. the difference between EV and PV at day 5 according to Table 2). Logically, the expression in time units provides a clearer view on the occurred delay than that in monetary terms. The ES concept also eliminates the anomalous behavior of the EVM schedule indicators, as the horizontal projection of EV onto the PV curve can only equal BAC at the end of the project. Furthermore, the Schedule Variance is expressed in units of time (for example, days). Studies by Vandevoorde and Vanhoucke (2006) and Vanhoucke and Vandevoorde (2007) showed that the performance measures of Schedule Variance and Schedule Performance Index based on ES, which are denoted by $SV_{(t)}$ and $SPI_{(t)}$, are the best indicators for project schedule assessment when using EVM data. Moreover, Batselier and Vanhoucke (2015b) came to similar conclusions based on their real-life project database (Batselier & Vanhoucke, 2015a). Note that this empirical database can be consulted freely at www.or-as.be/research/database.

EARNED SCHEDULE DIFFICULTIES

One of the criticisms on ES is that it still utilizes cost values (PV, EV, BAC) as proxies for time values. This criticism might have created difficulties on understanding the concept and has hindered the dissemination of ES use in many projects. Nevertheless, the criticism is justified, as the ES outcomes indeed depend on the cost values from project planning. This means that, after all, the ES-based schedule performance indicators can still exhibit a significant dependence on these monetary values. Furthermore, projects with planned outages (e.g. vacation, planned waiting time, concrete curing time) may produce ES values and indicators that are clearly out of context. The website www.earnedschedule.com offers an additional solution in the form of an Excel spreadsheet for these specific cases.

We now provide a demonstration of the problem that can arise from the use of ES on projects that are not suitable for analysis by this technique. Figure 9 shows the schedule for a notional project with four activities. The first two activities were executed according to plan. The third activity, which is on the critical path, was not yet initiated at the status date (i.e. March 13, 2015, represented by the vertical dashed red line).
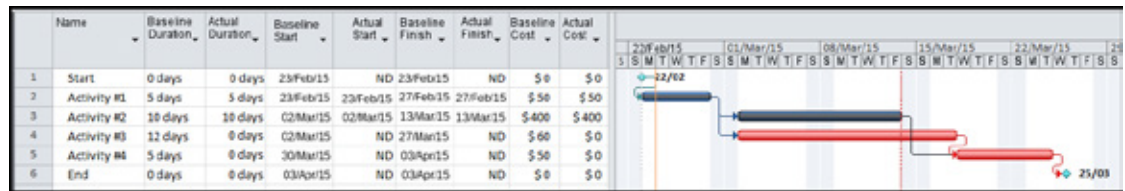
Figure 9: Gantt chart of an example project

Table 3 and the associated graph of Figure 10 were generated based on the Gantt chart of Figure 9. The table shows the PV and EV for each activity and for the entire project. The PV and EV curves are displayed in Figure 10. The figure also exhibits the values for ES (approximated) and SPI$_{(t)}$ (calculated).

Working Days		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Activity #1	PV	0	10	20	30	40	50																		
	EV	0	10	20	30	40	50																		
Activity #2	PV	0						40	80	120	160	200	240	280	320	360	400								
	EV	0						40	80	120	160	200	240	280	320	360	400								
Activity #3	PV	0						5	10	15	20	25	30	35	40	45	50	55	60						
	EV	0																							
Activity #4	PV	0																		10	20	30	40	50
	EV	0																						
Project	PV	0	10	30	60	100	150	195	285	420	600	825	1095	1410	1770	2175	2625	2680	2740	2750	2770	2800	2840	2890
	EV	0	10	30	60	100	150	190	270	390	550	750	990	1270	1590	1950	2350							

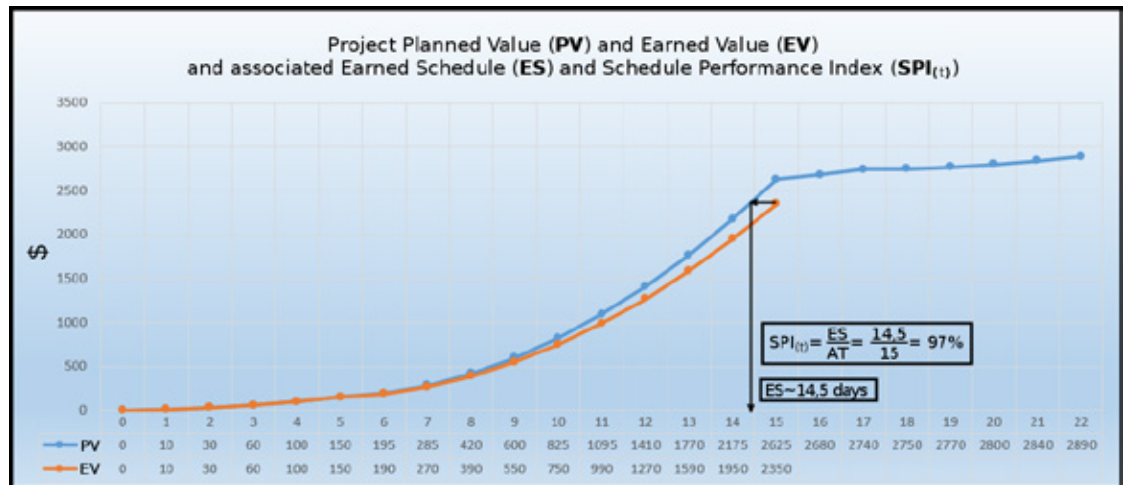Table 3: EVM metrics for an example project

Figure 10: EVM/ES metrics for an example project

Here, an important point of concern is that activities #3 and #4, which both lie on the critical path, have not even started at the status date, whereas activity #3 should in fact be nearly completed. Yet, according to the SPI$_{(t)}$, schedule performance is around 97%. Considering the significant lengths of these two critical activities and the current progress of activity #3, this level of performance does not accurately reflect reality.

EARNED DURATION CONCEPT

The Earned Duration (ED) concept (Khamooshi & Golafshani, 2014) was created to address the shortcomings of ES due to the usage of cost-based data as proxies for assessing the schedule performance of projects. Its foundation lies in the exclusive usage of time-based data for the generation of physical progress indicators. Thus, schedule performance indicators become free from any dependency on planned cost values, and therefore, are no longer influenced by them. For the presentation of the EDM methodology, it is important to come to an initial understanding of the concepts of activity duration, project duration and total duration under the new paradigm. These concepts were used to generate the Actual and Earned numbers shown in Table 4 for a notional project that contains three activities.

		Working Days												**Duration**	**Daily Ratio**
		1	2	3	4	5	6	7	8	9	10	11	12		
Activity 1	Planned	1	1	1	1									4.00	
		1.00	1.00	1.00	1.00										
	Actual		1	1	1	1	1	1	1	1				8.00	0.50
	Earned		0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50					
Activity 2	Planned			1	1	1	1							4.00	
				1.00	1.00	1.00	1.00								
	Actual			1	1	1	1	1	1					6.00	0.67
	Earned			0.67	0.67	0.67	0.67	0.67	0.67						
Activity 3	Planned			1	1	1	1	1	1	1	1			8.00	
				1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00				
	Actual								1	1	1	1	1	5.00	1.60
	Earned								1.60	1.60	1.60	1.60	1.60		
Total Duration — Planned	Daily	1.00	1.00	3.00	3.00	2.00	2.00	1.00	1.00	1.00	1.00	0.00	0.00		
	Cumulative	1.00	2.00	5.00	8.00	10.00	12.00	13.00	14.00	15.00	16.00	16.00	16.00		
Total Duration — Earned	Daily	0.00	0.50	1.17	1.17	1.17	1.17	1.17	2.77	2.10	1.60	1.60	1.60		
	Cumulative	0.00	0.50	1.67	2.83	4.00	5.17	6.33	9.10	11.20	12.80	14.40	16.00		

Table 4: EDM metrics for an example project

From close examination of Table 4, one can understand the duration "accounting" process for the planned and actual progress of the activities at each working day. The planned numbers result from assigning one time unit to each day of each activity and adding up all those numbers for a certain working day (column) to reach the Total Planned Duration (TPD) numbers (daily and cumulative) at the bottom. By definition, each planned day of an activity has a weight of one, regardless of the effort, resources or costs involved in its execution. Also, the Actual Duration of an activity i (AD_i) is the number of working days it actually took to complete it. To calculate the value of the daily ED for each activity effectively carried out in a working day, one must divide the Planned Duration of the activity (PD_i) by its AD_i. For example, activity 1 had a PD_1 of 4 working days and was completed in 8 days ($AD_1 = 8$). This means that the activity effectively contributes to the project's ED with 4/8 = 0.5 days for each day of its execution. For activity 2, which was planned to last 4 days ($PD_2 = 4$) and was conducted in 6 days ($AD_2 = 6$), each day of this activity's execution contributes to the project's total daily ED with 4/6 = 0.67 working days. For activity 3, the said contribution is 1.60 days per day of its execution. The sum of the daily EDs of a certain activity i defines the Earned Duration of that activity (ED_i). Note that, in the above discussion, we considered the PD_i, AD_i and ED_i at project completion (maximum values). However, these metrics can be calculated at any time instance (working day) during the project for schedule performance evaluation purposes (see later). For example, the sum of the daily EDs of a certain activity i, *up to a specific point in time*, defines the ED_i of that activity *at that time*, which is not necessarily the maximum value.

Furthermore, it is worth noticing that, similar to EVM's BAC, EDM exhibits a Total Duration at Completion (TDC). While the BAC is the sum of all planned activity costs (i.e. PV sum), the TDC is the sum of all planned activity durations (i.e. PD_i sum). Achieving the TDC would indicate the completion of the project. The two EDM project progress graphs are now presented in Figure 11.
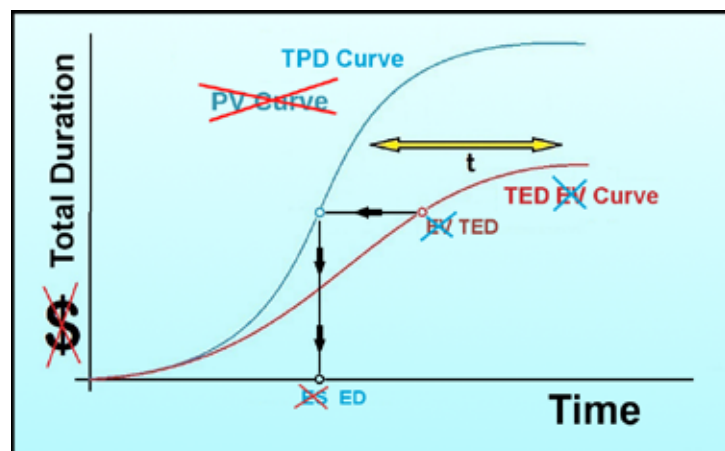

Figure 11: Similarity between ED and ES calculation

From Figure 11, the similarity between the ED and ES graphs becomes obvious. "Total Duration" (units of time) replaces "$" (costs) on the vertical axis, while Total Earned Duration (TED) substitutes EV and Total Planned Duration (TPD) does the same for PV. The formulas for the new metrics are provided in Table 5. The table also explicitly shows the correspondence between EDM and EVM/ES metrics.

EDM Acronym	Description	Equation	EVM Acronym	Description	Equation
ED	Earned Duration	See above	ES	Earned Schedule	See above
AD	Actual Duration	N.A.	AT	Actual Time	N.A.
TED	Total Earned Duration	$\sum_{i=1}^{n} ED_i$	EV	Earned Value	$\sum_{i1}^{n} EV_i$
TPD	Total Planned Duration	$\sum_{i=1}^{n} PD_i$	PV	Planned Value	$\sum_{i=1}^{n} PV_i$
TAD	Total Actual Duration	$\sum_{i=1}^{n} AD_i$	AC	Actual Cost	$\sum_{i=1}^{n} AC_i$
DPI	Duration Performance Index	$\dfrac{ED_{(t)}}{AD}$	$SPI_{(t)}$	Schedule Performance Index (ES)	$\dfrac{ES_{(t)}}{AD}$
EDI	Earned Duration Index	$\dfrac{TED}{TPD}$	SPI	Schedule Performance Index	$\dfrac{EV}{PV}$
TDV	Total Duration Variance	$TED - TPD$	SV	Schedule Variance	$EV - PV$

Table 5: Summary of EDM and EVM/ES metrics

The i subscript in the equation columns of Table 5 are meant to represent the numbering of project activities (with a maximum number of *n*). Also note that the Actual Duration (AD) represents the same metric as the AT used for ES calculations (but it is different from AD_i, the actual duration of an activity *i*). However, the former denomination seems to be more appropriate in the EDM context. Because of the mentioned similarity between the ED and ES concepts, the ES calculation principles can also be applied for EDM, that is, with the necessary adjustments. We refer to Figure 12.
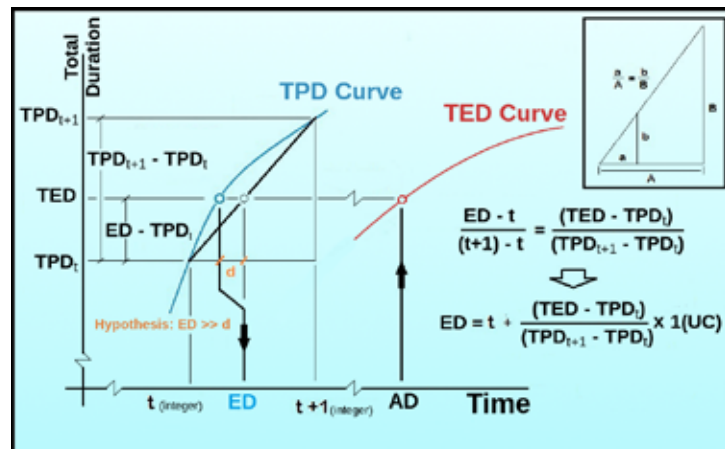

Figure 12: Detailed ED calculation

According to Figure 12, the equation for ED is:

$$ED = t + \frac{TED - TPD_t}{TPD_{t+1} - TPD_t} \times 1(UC)$$

Here, *t* has the same meaning as in the ES equation, and all other metrics are described above.

The ED schedule performance measures are also exhibited in Table 5, together with those based on EVM/ES. Again, it is easy to see the similarity between the equations for both sets of indicators.

ES AND ED ANALYSIS ON A NOTIONAL PROJECT

The Gantt chart of Figure 13 presents the data of a notional project executed in Microsoft Project. This project was developed with the intention of exacerbating some of the potential differences in results when applying EDM and EVM/ES to the same project schedule. The schedule covers the entire interval from project start to finish. The most important feature in this diagram is that activity #7 had its start delayed for 23 days and was only completed two days before the status date (on November 7, 2014). All other activities were performed perfectly according to plan.
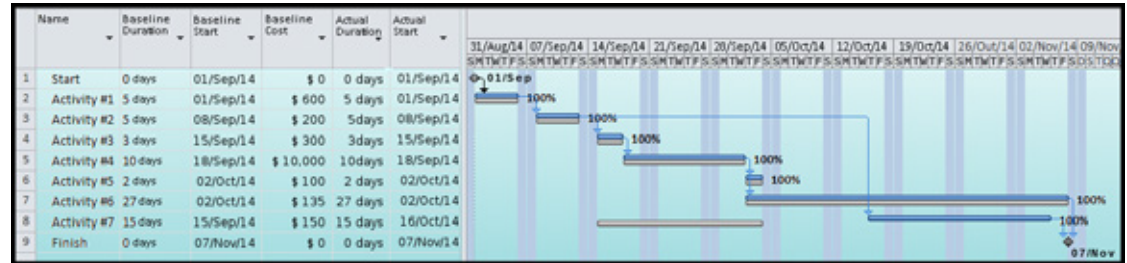

Figure 13: Gantt chart of a notional project

The following analysis assumes that the costs are linearly distributed over time for each activity in both planning and execution phase.

Based on the Gantt chart of Figure 13 and the cost distribution assumptions, the values for the relevant EVM/ES and EDM metrics and indicators are calculated. The results are presented in Table 6 and visualized in Figure 14.

| Time (Days)	PV ($)	AC ($)	EV ($)	SPI	ES (days)	SPI$_{(t)}$	TPD (days)	TED (days)	ED (days)	DPI
0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	120	120	120	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10	800	800	800	1.00	10.00	1.00	10.00	10.00	10.00	1.00
11	910	900	900	0.99	10.91	0.99	12.00	11.00	10.50	0.95
12	1,020	1,010	1,000	0.98	11.82	0.98	14.00	12.00	11.00	0.92
13	1,130	1,120	1,100	0.97	12.73	0.98	16.00	13.00	11.50	0.88
14	2,140	2,130	2,100	0.98	13.96	1.00	18.00	14.00	12.00	0.86
23	11,230	11,220	11,100	0.99	22.87	0.99	36.00	23.00	16.50	0.72
24	11,295	11,285	11,155	0.99	22.93	0.96	39.00	25.00	17.50	0.73
25	11,360	11,350	11,210	0.99	22.98	0.92	42.00	27.00	18.50	0.74
26	11,365	11,365	11,215	0.99	22.99	0.88	43.00	28.00	19.00	0.73
27	11,370	11,370	11,220	0.99	22.99	0.85	44.00	29.00	19.50	0.72
36	11,415	11,425	11,295	0.99	24.00	0.67	53.00	41.00	24.67	0.69
37	11,420	11,430	11,310	0.99	24.23	0.65	54.00	43.00	26.00	0.70
38	11,425	11,435	11,325	0.99	24.46	0.64	55.00	45.00	28.00	0.74
39	11,430	11,440	11,340	0.99	24.69	0.63	56.00	47.00	30.00	0.77
40	11,435	11,445	11,355	0.99	24.92	0.62	57.00	49.00	32.00	0.80
41	11,440	11,450	11,370	0.99	27.00	0.66	58.00	51.00	34.00	0.83
47	11,470	11,480	11,460	1.00	45.00	0.96	64.00	63.00	46.00	0.98
48	11,475	11,485	11,475	1.00	48.00	1.00	65.00	65.00	48.00	1.00
49	11,480	11,480	11,480	1.00	49.00	1.00	66.00	66.00	49.00	1.00
50	11,485	11,485	11,485	1.00	50.00	1.00	67.00	67.00	50.00	1.00

Table 6: EVM/ES and EDM metrics for a notional project
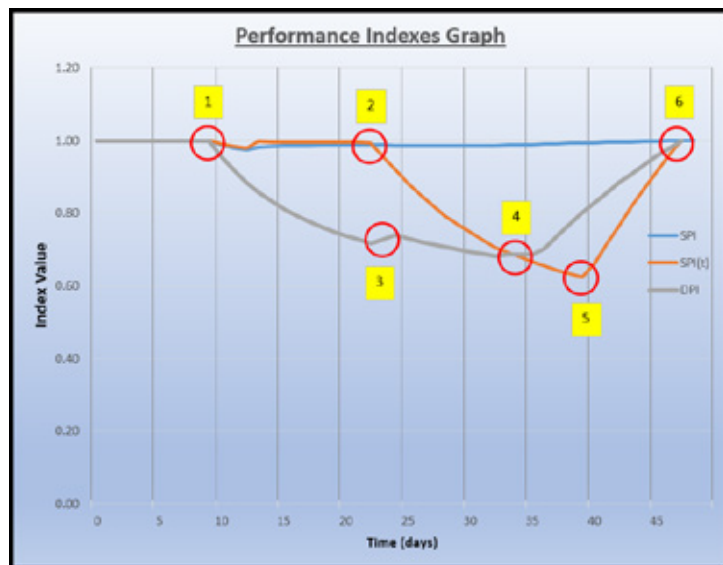
Figure 14: EVM/ES and EDM performance index graphs for a notional project

Figure 14 also provides a basis for comparison of the performance indexes SPI (from EVM), $SPI_{(t)}$ (from ES), and DPI (from EDM) along the 50 days of project execution. The red circles in this graph mark six points of interest (PoI) for the analysis. Furthermore, we will restrict the analysis to the comparison of ES and ED performance indexes, since EVM's SPI exhibits almost no change over the entire project and the performance of the indicator has been shown to be inferior to that of $SPI_{(t)}$ in multiple studies (Batselier & Vanhoucke, 2015b; Vandevoorde & Vanhoucke, 2006; Vanhoucke & Vandevoorde, 2007).

The first PoI (1) occurs on day 10 of the project, where activity #7 started to be delayed. The cost rate for this activity is $10/day. At this point, the ES performance index $SPI_{(t)}$ initiates a downward slope that lasts for about three days and reaches the minimum value of 0.98, which is not a substantial change. However, the ED performance index DPI readily identifies the problem and begins to fall with strong inclination and reaches 0.88 after three days. The project manager (PM) that receives the information from the $SPI_{(t)}$ may simply conclude that there is no indication of any problem with the project schedule. On the other hand, should the PM receive the DPI, he/she would probably decide that schedule problems are imminent. The DPI thus seems to respond quickly to problems in the schedule, even within a few days. Moreover, during the following days, the negative trend of DPI continues, signifying a progressive delay in the project execution. The PM will thus be urged to address the schedule problem. Interestingly, the $SPI_{(t)}$ practically gets back to 1 after day 13, leaving the PM ignorant of the schedule problem.

The second PoI (2) takes place on day 23, when the $SPI_{(t)}$ starts to record the delay of activity #7. That is, it took 13 days after the beginning of the delay for the $SPI_{(t)}$ to really start showing the schedule risk. One explanation for this lateness on reporting is related to the relatively low daily cost rate ($10/day) of activity #7 as compared to that of activity #4 ($1,000/day) and activity #3 ($100/day). As such, the contribution of activity #7 to the project $SPI_{(t)}$ is effectively masked. The authors' experience as project managers shows that differences in daily cost rates across activities of magnitudes from 10 to 100 actually occur quite often in real-life. An inspection of a sample of seven projects from the empirical project database of Batselier and Vanhoucke (2015a) confirmed that a factor 10 is frequent and that a factor 100 occurs occasionally (activities with a cost rate of $0.00/day are obviously excluded). Back to Figure 14, the DPI continues to exhibit very low values (i.e. between 0.70 and 0.75) during a large portion of the project. It, therefore, keeps indicating poor schedule performance.

The third PoI (3) is related to the period from day 23 to day 25, in which the DPI reflects a schedule performance improvement due to the start of activity #5 as it was planned. At the same time, the $SPI_{(t)}$ records nothing. At day 23, activity #4, which has a high relative value ($1,000/day), stops influencing the $SPI_{(t)}$ calculation. Thereafter, the 13 days of delay of activity #7 (total of $130) begin to show up in the $SPI_{(t)}$ calculation, which results in a downward trend of the index value. Nevertheless, activity #5's execution according to plan ($50/day) during the same period causes very little change to the $SPI_{(t)}$ curve. It should also be emphasized that after the day 23-25 period, the DPI returns to its downward trend, which reflects the continued delay of activity #7's start.

The fourth PoI (4) is on day 34 when the delayed activity #7 eventually commences. Observe that on this day, the DPI interrupts its downward trend and begins recording the execution of this activity, while the $SPI_{(t)}$ continues its downward trend until day 40. Once again, the DPI immediately registers that there is a project status change with respect to schedule, whereas the $SPI_{(t)}$ postpones this information for the PM. The DPI directly begins registering schedule recovery because it is not affected by the costs of the activities. The fifth PoI (5) is situated on day 40, at which the $SPI_{(t)}$ begins recording the inversion of the project schedule trend and starts displaying a recovery of the schedule performance. It should be noticed that it took 6 days from the eventual start of the delayed activity #7 for $SPI_{(t)}$ to begin indicating the recovery of the project in terms of duration.

Finally, the last PoI (6), day 48, represents the point when all project activities get back on track and the project is on course for a timely finish. All activities are completed here, except for activity #6, which is progressing as planned. At this point, both $SPI_{(t)}$ and DPI reach the value of 1, meaning that project execution is, at last, according to plan.

CONCLUSIONS AND RECOMMENDATIONS
In spite of all the attention and effort dedicated to the issue of managing a project schedule, up to the beginning of this century, the main schedule evaluation technique still consisted of comparing the status of each activity against its planned progress. PMs traditionally resorted to the dissection of the project's Work Breakdown Structure (WBS), the Gantt chart timetable, and the network diagram. Then, upon finding discrepancies, they performed lengthy discussions on the problem and on how it could best be reported to upper management. This process was commonly tedious and very time- and resource-consuming, and yet, it frequently lacked the ability to convey the project schedule status message in a way that executives could clearly and swiftly understand the problem and approve the solution proposed. The same kind of problem was faced in the area of project cost management, but there, much success was achieved with the development and practice of EVM.

The ES technique, based on the EVM methodology, has been deemed the best alternative to simplify the management of project schedule. However, as demonstrated in this paper, the fact that it uses cost data as proxies for time values makes it the subject of possible improvements. By means of notional examples, we have demonstrated the strengths of the EDM technique of Khamooshi and Golafshani (2014) as an alternative to ES. These are: the high responsiveness to changes in activity execution; the simplicity of data collection (most data are promptly available from EVM data); the independency from activity costs; the similarity to known ES calculations; and the natural understandability of the obtained results.

It is the authors' belief that EDM is bound to replicate the EVM success in project cost management for the project schedule environment. However, the authors also understand the difficulties involved with the absorption and comprehension of the new concepts introduced by EDM. One of the authors had extensive dialogues on the subject with professionals in the field and perceived that the new concepts, especially total duration, are rather difficult to assimilate.

There is a definite need for demonstrating the power of EDM; by extensive research and experimentation, as well as through the development of an educational methodology, presentations, tutorials and software tools to assist in the acceptance and dissemination of the new technique.

EDM has yet to be scrutinized by extensive research to validate its seemingly promising potential. Some academic research on the subject is already being performed (Batselier & Vanhoucke, 2015c). With the current article, the authors also hope to foster PMs that like to explore new techniques to be the first to test EDM in practice, and thus, contribute to the knowledge advancement in project schedule management.

References

Batselier, J., & Vanhoucke, M. (2015a). Construction and evaluation framework for a real-life project database. *International Journal of Project Management, 33* (3), 697-710.

Batselier, J., & Vanhoucke, M. (2015b). Empirical evaluation of earned value management forecasting accuracy for time and cost. *Journal of Construction Engineering and Management*, http://dx.doi. org/10.1061/(ASCE)CO.1943-7862.0001008.

Batselier, J., & Vanhoucke, M. (2015c). Evaluation of deterministic state-of-the-art forecasting approaches for project duration based on earned value management. *Submitted to an international journal.*

Christensen, D. S. (1990). The Role of Analysis in C/SCSC. *Program Manager Magazine*, July - August, pp. 26-33.

Dinsmore, P. C., & Silveira Neto, F. H. (2004). *Gerenciamento de Projetos - Como Gerenciar seu Projeto com Qualidade, dentro do Prazo e Custos Previstos*. Rio de Janeiro: Qualimark Editora Ltda.

Fleming, Q. W., & Koppelman, J. M. (2010). *Earned Value Project Management* (4 ed.). Newtown Square, Pennsylvania: Project Management Institute.

Fondahl, J. W. (1987). The History of Modern Project Management – Precedence Diagramming Methods: Origins and Early Development. *Project Management Journal*, 18, 33-36.

Gantt, H. L. (1919). *Organizing For Work*. New York: Allen & Unwin.

Goldratt, E. (2002). Critical Chain – *A Business Novel*. Great Barrington, Massachusetts: North River Press.

Hamilton, L. R. (1964). *Study of Methods for Evaluation of The PERT/COST Management System*. Mitre Corporation.

Khamooshi, H., & Golafshani, H. (2014). EDM: Earned Duration Management, a new approach to schedule performance management and measurement. *International Journal of Project Management*, 32 (6), 1019-1041.

Lipke, W. (2003). Schedule is Different. *The Measurable News*, March, pp. 10-15.

Lipke, W. (2009). *Earned Schedule* (1 ed.). Lulu Publishing.

Solanki, P. (2009). *Earned Value Management: Integrated View of Cost and Schedule Performance* (1 ed.). Global India Publications Pvt Ltd.

Stevenson, J. P. (2001). *The $5 Billion Misunderstanding: The Collapse of the Navy's A-12 Stealth Bomber Program* (1 ed.). Annapolis, Maryland: US Naval Institute Press.

Vandevoorde, S., & Vanhoucke, M. (2006). A comparison of different project duration forecasting methods using earned value metrics. *International Journal of Project Management*, 24 (4), 289-302.

Vanhoucke, M. (2010). *Measuring Time - Improving Project Performance using Earned Value Management* (Vol. 136 of International Series in Operations Research and Management Science). Springer.

Vanhoucke, M. (2011). On the dynamic use of project performance and schedule risk information during project tracking. *Omega - International Journal of Management Science*, 39, 416-426.

Vanhoucke, M. (2014). *Integrated Project Management and Control: First comes the theory, then the practice* (Vol. of Management for Professionals). Springer.

Vanhoucke, M., & Vandevoorde, S. (2007). A simulation and evaluation of earned value metrics to forecast the project duration. *Journal of the Operational Research Society*, 58, 1361-1374.