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Using Earned Value Management for More Sustainable Project Schedule Control

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Abstract:

Research Question: The aim of this paper is to provide a state-of-science review and offer a critical analysis of contemporary schedule related Earned Value Management (EVM) approaches. **Motivation:** Since the introduction of the EVM as a tool for project control in the late 1960s, academics have tried to improve its best application. Although this method significantly contributed to efficient cost management, application of EVM to schedule management was falling behind. A significant effort has been made to improve its usability for project time management, which resulted in a dramatic evolution. The paper builds on existing literature and earlier studies, adding value with the inclusion of the cost-based and time-based approaches for assessing project schedule performance. **Idea:** The idea of this paper was to evaluate some of the most significant EVM schedule control methods and identify open issues. The main study hypothesis is that the most recent approaches provide a more reliable forecast and thus a solid ground for further improvements. **Data:** A case study in the form of a simplified project was used to illustrate how different contemporary approaches compare in terms of conceptualization, methodological issues, and theoretical underpinnings. **Tools**: A combination of statistical analysis and Monte Carlo simulation was used to evaluate the performance of different EVM approaches. Microsoft Excel was used for data processing, Microsoft Project and SATA software for data visualization, and Oracle Crystal Ball for Monte Carlo simulation. **Findings:** Quantitative analysis confirmed that the project-specific Earned Duration Management (EDM) and Earned Schedule (ES) approaches provide sustainable and more accurate results during the whole projects lifespan, while forecasts obtained by more traditional methods proved to be unreliable in the later stages of the project. While practical application generally lags after the growing theory, the latest literature paves the way to the integration of EVM and risk management making the contemporary EVM approaches stochastic and therefore more realistic. **Contribution:** The results of this study can be used as a basis for introducing advanced and generally more usable EVM models, which will improve the project schedule control.

Keywords: earned value; project duration forecasting; earned schedule; earned duration.

JEL Classification: C53, O22

1. Introduction

Although effective project control involves the use of many methods and techniques, just a few of them have experienced such evolution as the Earned Value Management. Developed in 1967 by the US Department of Defence as the Cost / Schedule Control System Criteria (Christensen, 1990) and later renamed to Earned Value Management (EVM) in the late 1970s (Fleming & Koppelman, 2010), the method earned its true fame in the early 1990s. One of the reasons for the increased attention was the cancellation of the US Navy Avenger II program due to the inability to achieve time and costs targets, which was detected by EVM (Stevenson, 2001).

The primary goal of EVM is measuring and forecasting actual progress on the project by integrating cost, time, and scope as three key elements of project management. The method considers the work done, the time spent, and the costs incurred to assess the progress of the project based on monetary units. The basic principles of the method and its possible application are broadly represented by many authors (e.g. Anbari, 2003; Fleming & Koppelman, 2010).

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Despite the fact that EVM was originally developed for monitoring project costs and time, most of the research effort and application was related solely to cost management. The reason for the less successful implementation in the field of schedule management lies in the nature of the original indicators whose usability decreases in later phases of projects that miss the original deadline. The inability to ensure consistency between forecasted and actual values throughout the whole project significantly limited the use of the EVM exclusively to cost management for decades.

The limited use of EVM for project time management reduced the opportunity of reaching a full potential of sustainable project management. This implies performing a project as efficiently as possible, minimizing different kinds of waste. In other words, benefits of sustainable EVM approach stretch beyond the project schedule control, and include having less waste, reduced delivery costs, better use of resources and their skills, economies of mass production, etc.

In the last fifteen years several significant efforts have been made towards a wider application of the EVM in the field of project time management. Some of the key events in this process were the development of planned value method (Anbari, 2003), earned schedule method (Lipke, 2003), earned duration method (Jacob & Kane, 2004) and earned duration management (Khamooshi & Golafshani, 2014), which created an opportunity for further improvements.

Application of new methods requires the use of different types of inputs and complex calculations, which further questions their actual usability in practice. The goal of this paper is to clarify the application of the most significant methods and evaluate their major benefits and drawbacks using a simplified case study. Quantitative evaluation of major scheduling approaches, including the one suggested by Khamooshi & Golafshani (2014), aims to contribute to better understanding and thus selection of the appropriate approach. This should further result in a more accurate forecast and successful application in practice.

The paper is structured as follows. The second section represents an introduction to the concept of the EVM, which is followed by four major and some minor improvements related to project schedule management. The third section provides information on methodology used and the description of the simplified project data used for the case study. The last part of the paper includes a practical demonstration of methods, discussion, and a critical review of the obtained results. The paper concludes with additional observations and recommendations for practitioners.

2. Theoretical Background

In this section, the most important theoretical concepts used in this study are discussed. For the sake of clarity, issues related to basic scheduling concept, major improvements, and minor improvements of contemporary approaches were grouped together. Finally, Table 1 summarizes the concepts used in this paper.

2.1 Issues related to basic scheduling concept

To evaluate project progress EVM calculates two widely known schedule performance indicators, the schedule performance index (SPI) and the schedule variance (SV). The SV compares the amount of work done in relation to the amount of work planned, which is calculated as the difference between the earned and planned value, i.e. SV = EV – PV. This is illustrated in Figure 1 (Ismael, 2013). The SPI measures the efficiency of the work, which is calculated as the ratio between the earned value and planned value, i.e. SPI = EV / PV.

Although expressed as monetary value, interpretation of the SV is straightforward. If SV < 0, the project is behind plan as the amount of work earned is lower than planned. Similarly, if SV > 0, the project is ahead of plan as the amount of work earned is higher than planned. If SV = 0, the earned work equals planned, which means that the project is executed according to schedule. When the project is completed, the EV equals PV, which means that SV always tends to zero.

Since SPI uses the same inputs as SV, interpretation is very similar. If SPI > 1, the schedule efficiency is higher than planned. Likewise, SPI = 1, means efficiency is equal, and if SPI < 1, efficiency is lower than planned. When the project is completed, the SPI always equals 1. The behaviour of these two indicators was often criticized by many academics and stated as the main reason for insufficient use in practice.

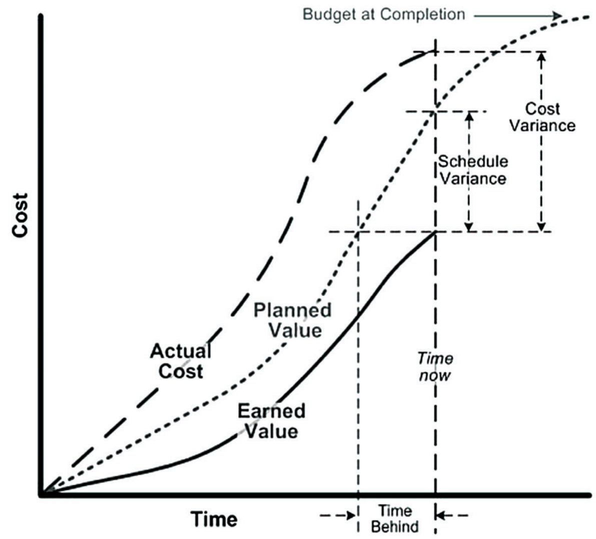


Figure 1: Illustration of the basic EVM concept
Source: Adapted from Ismael, 2013

The problem has three dimensions: (1) over the last third of the project SV and SPI indicators become unreliable since SV always converges to 0 and SPI to 1; (2) SV is not represented in time units, rather in monetary units; (3) SV = 0 or SPI = 1 could mean that work is completed, but also that execution is performed as planned. Finally, the EVM concept considers the linear projection of the activity duration ignoring the situation that the corresponding percentage of the activity duration may require a larger amount of work (Browning, 2019).

2.2 Major improvements of EVM scheduling concept

Described drawbacks led to the development of several improvements of EVM in the past two decades. Anbari (2003), Lipke (2003), Jacob & Kane (2004) and Khamooshi & Golafshani (2014) suggested several key modifications of schedule indicators, and some of their usability was later evaluated and confirmed in the series of articles (Vandevoorde & Vanhoucke, 2006; Vanhoucke & Vandevoorde, 2007; Lipke, 2009; Vanhoucke et al., 2015; Avlijas et al., 2015; Batselier & Vanhoucke, 2015a; Batselier & Vanhoucke, 2015b). These new approaches have made possible further improvements described in section 2.3, whose evaluation lasts to this day. The following part summarizes some of the key modifications and demonstrates their usability on a simplified project data.

2.2.1. The Planned Value Method (PVM)

Anbari (2003) stated that the SV can be translated into time units by introducing the Planned Value Rate. The Planned Value Rate is calculated as the ratio of budget at competition (BAC) and planned duration (PD). In other words, PV Rate = BAC / PD and represents the average planned value per duration period. SV presented in time units was named Time Variance (TV), and is calculated as follows:

$$TV = SV / PV\ Rate = (SV \times PD) / BAC = (EV - PV) \times PD / BAC \quad (1)$$

Vandevoorde and Vanhoucke (2006) presented a generic formula for estimated project duration as:

$$EAC(t)pv = AD + PDWR \quad (2)$$

EAC(t) represents the estimated project duration, AD the actual duration and PDWR the planed duration of the work remaining. Since PDWR is estimated and depends on project characteristics, some authors distinguish three scenarios that can be applied in situations where the project is not facing irreversible problems i.e. where schedule planning can be useful. These scenarios are: PDWR is according to plan, PDWR follows SPI trend and PDWR follows SCI trend.

Although general overview of these measures can be found in the literature (Vandevoorde & Vanhoucke, 2006), the two most common scenarios that will be considered in this paper are PDWR is according to plan and PDWR follows SPI trend. The rest of the paper denotes the forecasts that use the first scenario as EAC(t)_1 and the forecasts that use the second scenario as EAC(t)_2. According to the described nature of

PDWR, the following forecasting formulas can be derived for the planned value method:

$$EAC(t)pv1 = PD - TV = PV - (EV - PV) \times PD / BAC \quad (3)$$

$$EAC(t)pv2 = PD / SPI \quad (4)$$

2.2.2. The Earned Duration Method (ED)

The approach suggested by Jacob and Kane (2004) was named "Earned Duration Method" as it uses earned duration (ED) to calculate estimated project duration (EAC(t)). The earned duration is calculated as the product of actual duration and schedule performance index (ED = AD x SPI). Therefore, the generic formula for estimated project duration by this approach can be given as:

$$EAC(t)ed = AD + (PD - ED) / PF = AD + (PD - AD \times SPI) / PF \quad (5)$$

Performance factor (PF) can be used to account for the project characteristics, i.e. two already described scenarios (PDWR is according to plan, PF = 1; PDWR follows SPI trend, PF = SPI):

$$EAC(t)ed1 = AD + (PD - ED) / 1 = PD + AD \times (1 - SPI) \quad (6)$$

$$EAC(t)ed2 = AD + (PD - ED) / SPI = PD / SPI \quad (7)$$

In cases where the project is not complete and surpasses the planned duration (PD), in the above-mentioned formulas PD should be substituted by the actual duration (AD):

$$EAC(t)ed1 = AD + (AD - ED) / 1 = AD \times (2 - SPI) \quad (8)$$

$$EAC(t)ed2 = AD + (AD - ED) / SPI = AD / SPI \quad (9)$$

2.2.3. The Earned Schedule Method (ES)

The earned schedule method was proposed by Lipke (2003) and later improved by Lipke (2009; 2011) and Elshaer (2013). According to this method, EV at review point is traced backwards or forwards to the PV (schedule baseline). In other words, earned schedule (ES) includes identification of PV increment in which EV occurs. This way EV is translated into time units and compares real performance to expected performance. The formula for earned schedule can be defined as: $ES = n + (EV - PV_n) / (PV_{n+1} - PV_n)$, where n denotes the increment of the PV in time units that is lower than current PV, PV_n denotes PV at time n and PV_{n+1}represents PV at time n+1. The generic formula is:

$$EAC(t)es = AD + (PD - ES) / PF \quad (10)$$

As with the earned duration method, the performance factor (PF) can be used to account for two already described scenarios (PDWR is according to plan, PF = 1; PDWR follows SPI(t) trend, presented as PF = SPI(t)):

$$EAC(t)es1 = AD + (PD - ES) / 1 = AD + PD - ES \quad (11)$$

$$EAC(t)es2 = AD + (PD - ES) / SPI(t) \quad (12)$$

2.2.4. The Earned Duration Management (EDM)

Khamooshi and Golafshani (2014) created Earned Duration Management (EDM) to address the drawbacks of ES which uses cost-based data in assessing project schedule performance. EDM is based solely on time-based data for the generation of indicators of physical progress, and it replaces ES metric by Earned Duration (ED(t)). ED(t) represents the projection of the Total Earned Duration (TED - sum of the earned durations of all completed and in-progress activities at Actual Time) on Total Planned Duration (TPD - sum of the planned durations of all planned activities at Actual Time according to the baseline schedule).

$$ED(t) = t + (TED - TPD_t) / (TPD_{t+1(calendar\ unit)} - TPD_t) \quad (13)$$

In order to calculate expected duration based on EDM methodology, a formula very similar to the traditional PV method can be used (EAC(t)=PD/SPI). The only change represents the use of the duration performance index (DPI) as performance factor:

$$EAC(t)edm = PD/DPI \quad (14)$$

DPI indicates schedule performance and how the project is doing in relation to the target completion date. It is calculated and interpreted very similarly to SPI(t) as ED(t)/AD. As with the earlier methods, the performance factor (PF) can be used to account for two already described scenarios (PDWR is according to plan, PF = 1; PDWR follows DPI trend, PF = DPI):

$$EAC(t)edm1 = AD + (PD - ED(t)) / 1 = AD + PD - ED(t) \quad (15)$$

$$EAC(t)edm2 = AD + (PD - ED(t)) / DPI \quad (16)$$

2.3 Further improvements of scheduling concepts

To improve ES, Lipke et al. (2009) first applied the statistical method, and later extended the technique by considering schedule adherence, performance and occurrence of rework (Lipke, 2020). Elshaer (2013) suggested integration of EVM and schedule risk analysis (SRA) through the introduction of activity sensitivity information. Batselier and Vanhoucke (2017) integrated EVM with the exponential smoothing forecasting and developed eXponential Smoothing-based Method (XSM) that achieved performance comparable to the most accurate previous methods.

Ballesteros-Perez et al. (2019) proposed Earned Schedule min and Earned Schedule max to prioritize activities and allocate resources to shorten the duration of the project. Similarly, Hammad et al. (2018) suggested integration of the earned schedule with the theory of constraints, introducing buffer analysis according to task completion (project buffer and feeding buffer). Several researchers strived to change deterministic duration prediction using ES method into a probabilistic duration prediction (Anondho et al., 2018).

To improve the accuracy of the EDM method, de Andrade et al. (2019) introduced a forecasting approach that combines the schedule performance and schedule adherence of the project during execution. Khamooshi and Abdi (2016) have demonstrated the benefits of using the earned duration index (EDI) in combination with the already defined exponential smoothing technique to forecast a project completion date. De Andrade and Vanhoucke (2017) combined EDM and EVM and used ED and PV to produce an EDM-based project-level earned value (EVd).

Votto et al. (2020) suggested further improvement of EDM method and use of control charts to monitor deviations during project execution and to identify special sources of variation, interpreted as evidence of real risk of project delays. Roghabadi and Moselhi (2020) presented a new risk-based earned duration management model (RBEDM) for monitoring and estimating schedule performance of projects considering critical activities only and their associated risk factors. Another risk-related improvement included a new triangular intuitionistic fuzzy-EDM model to improve the applicability of time performance indices (Hamzeh et al., 2020).

One of the most recent improvements from aerospace industry include the Enhanced-Earned Value Management (E-EVM) model with a capacity to detect both delayed and advanced projects by converting times (hours) into monetary units (Lopez Pascual et al., 2021). Another recent study from construction industry proposed the application of ANN and mathematical models to earned value management to estimate the schedule indices, which provided excellent results (Mohammed et al., 2021). Besides risk related improvements and combining different methods, some of the recent studies go beyond schedule and cost constrains and include scope, quality, and resources (Liu & Jiang, 2020; Song et al., 2022).

Despite many suggested improvements in recent years, the general use of EVM is slowly gaining on importance in different industries and practitioners are trying to balance between advanced algorithms and their convenient application (Bryde et al., 2018). As the general goal is to keep it simple, this study focuses on the major approaches only. These are presented within Table 1.

Table 1: Inputs and terminology used in major approaches

Approach	Planned Value Method	Earned Duration Method	Earned Schedule Method	Earned Duration Management
Inputs	Cost-based data	Cost-based data	Cost-based data	Time-based data
Status of the project	PV Rate - Planned value rate	ED - Earned duration	ES - Earned schedule	ED(t) - Earned duration
	AT - Actual time	AD - Actual duration	AT - Actual time	AD - Actual duration
	SPI - Schedule performance index	SPI - Schedule performance index	SPI(t) - Schedule performance index time	DPI - Duration performance index
Indicator at competition (scenario dependent)	EAC(t)pv1 = PV – (EV – PV) × PD / BAC	EAC(t)ed1 = AD × (2 – SPI)	EAC(t)es1 = AD + PD – ES	EAC(t)edm1 = AD + PD – ED(t)
	EAC(t)pv2 = PD / SPI	EAC(t)ed2 = AD / SPI	EAC(t)es2 = AD + (PD – ES) / SPI(t)	EAC(t)edm2 = AD + (PD – ED(t)) / DPI

3. Research Approach and Methodology

To illustrate the key benefits and drawbacks of the major approaches, a case study in the form of a simplified production planning project was used. The goal of the case study approach is twofold. First, it provides insights into the nature of the required inputs, which further defines usability and reliability of the estimated project duration. Second, a controlled case provides a step-by-step analysis and illustrates how different kinds of deviation from schedule impact the accuracy of different forecasting methods.

3.1 Illustrative example

The goal of the production planning project is to achieve efficient and uninterrupted production flow by a timely product design, materials planning and control, organization of the production facilities (workforce, machines, etc.), achieving optimal allocation and scheduling of resources and coordination of different departments. The project consists of five activities and their attributes are given in Table 2.

Table 2: Sample project data

Task ID	Depends On	Planned Duration	Actual Duration	Baseline Start	Baseline Finish	Actual Start	Actual Finish	Baseline Cost
A	-	2 weeks	3 weeks	Week 1	Week 2	Week 1	Week 3	300,00
B	-	3 weeks	3 weeks	Week 1	Week 3	Week 1	Week 3	200,00
C	A	3 weeks	3 weeks	Week 3	Week 5	Week 4	Week 6	250,00
D	A	5 weeks	4 weeks	Week 3	Week 7	Week 4	Week 7	600,00
E	C	4 weeks	4 weeks	Week 6	Week 9	Week 8	Week 11	400,00

Product development and design (Task A) represents developing and designing a new product with all the features needed for its effective use. Forecasting (Task B) is the process of estimating future demand. The next step is the process planning and routing (Task C), which determines the specific technological steps and sequence in which products will be produced. This task is executed along with the material and tools planning (Task D), which determines the requirements of various tools, materials, and subassemblies. Finally, loading and scheduling (Task E) aim at assignment of jobs to different machines, and determination of timing and sequencing of the work.

As can be seen from Table 2 and Figure 2, the project was completed late. It took 11 weeks to complete the project instead of initial 9 weeks. According to Figure 2, the delay in activity A caused the late start of activities C and D. Activity D lasted 1 week less than planned, so the planned finish date was accomplished. On the other hand, delay in the critical activity C led to the late start of activity E. Additionally, due to an external factor, the start of activity E was postponed by additional 1 week, so the total delay in activity E was 2 weeks. Therefore, the critical points to be analyzed are week 4, and week 7, and special focus was put on these points. To calculate some of the indicators for the EDM approach, additional activity-based data were derived and presented in Table 3.

Figure 2: Tracking Gantt Chart for the project (black bars – planned, shaded bars – actual)

3.2 Methods and tools

Calculations and graphs presented within section 4 (Results and Discussion) were done using a Microsoft Excel and STATA software. Monte Carlo analysis and Oracle Crystal Ball software were used to evaluate the impact of potential extension of activity E on the performance of each of four forecasting methods, and both project scenarios. To quantify the differences in the accuracy of the suggested EVM approaches, the periodic forecasts were compared with the final project duration and evaluated by the following measure:

$$MAPE = \frac{1}{\#Periods} \times \sum_{Periods} \frac{|EAC(t) - RD|}{RD} \tag{17}$$

Mean Absolute Percentage Error (MAPE) represents the average of the absolute values of the relative deviations between the periodic time predictions (EAC(t)) and final project duration (RD). While the Mean Percentage Error (MPE) calculations can result in negative and positive values and measure over and underestimations of the final project duration, MAPE provides an indication on average deviations in nonnegative value (Vanhoucke, 2016).

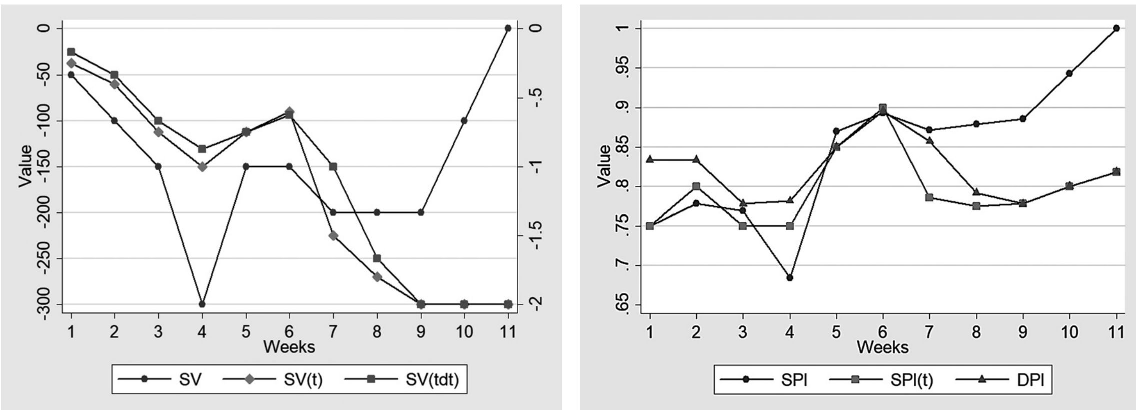
Table 3: Activity-based project data

	Weeks												
	1	2	3	4	5	6	7	8	9	10	11	Dur.	Ratio
Activity A													
Planned Value	150	150											
Planned Duration	1	1										2.00	
Actual Duration	1	1	1									3.00	
Earned Value	100	100	100										
Earned Duration	0.67	0.67	0.67										0.67
Activity B													
Planned Value	50	100	50										
Planned Duration	1	1	1									3.00	
Actual Duration	1	1	1									3.00	
Earned Value	50	100	50										
Earned Duration	1.00	1.00	1.00										1.00
Activity C													
Planned Value			50	150	50								
Planned Duration			1	1	1							3.00	
Actual Duration				1	1	1						3.00	
Earned Value				50	150	50							
Earned Duration				1.00	1.00	1.00							1.00
Activity D													
Planned Value			100	150	150	150	50						
Planned Duration			1	1	1	1	1					5.00	
Actual Duration				1	1	1	1					4.00	
Earned Value				100	200	200	100						
Earned Duration				1.25	1.25	1.25	1.25						1.25
Activity E													
Planned Value						100	100	100	100				
Planned Duration						1	1	1	1			4.00	
Actual Duration								1	1	1	1	4.00	
Earned Value								100	100	100	100		
Earned Duration								1.00	1.00	1.00	1.00		1.00
Weekly Total												**Project Total**	
Planned Value (PV)	200	250	200	300	200	250	150	100	100	0	0	1750	
Planned Duration (PD)	2	2	3	2	2	2	2	1	1	0	0	17	
Actual Duration (AD)	2	2	2	2	2	2	1	1	1	1	1	17	
Earned Value (EV)	150	200	150	150	350	250	100	100	100	100	100	1750	
Earned Duration (ED)	1.67	1.67	1.67	2.25	2.25	2.25	1.25	1.00	1.00	1.00	1.00	17	
Cumulative													
Planned Duration (PD)	2	4	7	9	11	13	15	16	17	17	17		
Earned Duration (ED)	1.67	3.33	5.00	7.25	9.50	11.75	13.00	14.00	15.00	16.00	17.00		

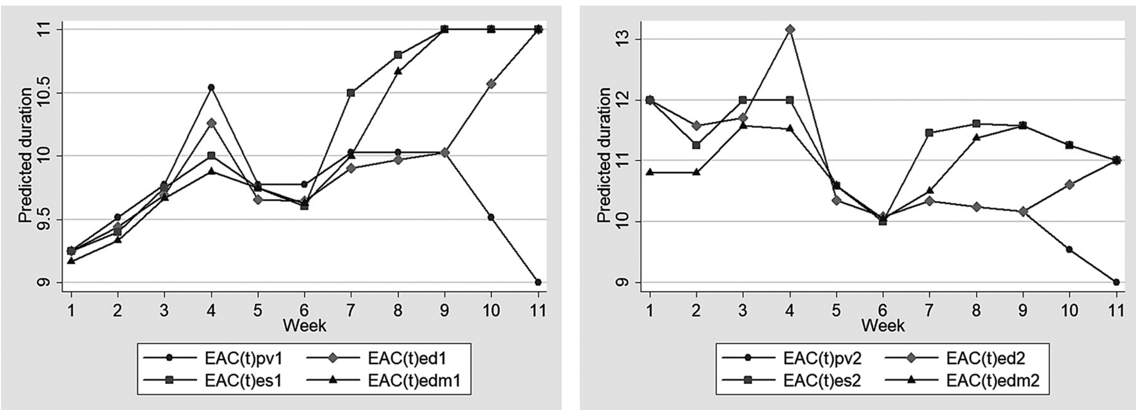
4. Results and Discussion

To compare the performance of four major approaches, all schedule related EVM indicators given within Table 1 were calculated. Figure 3a reveals that the cost-based Schedule Variance (SV) recorded a negative trend until week 4, which was followed by a positive trend, finally reaching a zero value. On the other hand, SV(t) and SV(tdt) indicators developed by Lipke (2003) and Khamooshi and Golafshani (2014), respectively, have a similar pattern, and show a negative trend that ends with a cumulative variance of 2 weeks, which represents the actual delay.

A similar effect can be attributed to Schedule Performance Index and Duration Performance Index (Figure 3b). During the early stage (first 3 weeks) and middle stage (next 3 weeks), all three measures exhibit similar values. However, within the last project phase (at the ca. 60% of completion), the SPI becomes unreliable and indicates improvement while the project continues to lag. This schedule decline is clearly illustrated by the SPI(t) and DPI indicators.



(a)(b)**Figure 3:** (a) SV, SV(t), SV(tdt); (b) SPI, SPI(t), DPI



(a)(b)**Figure 4:** (a) PF=1; (b) PF= SPI, SPI(t), DPI

Figures 4a and 4b display four different schedule forecasting methods in two different project scenarios (PF=1 and PF follows SPI/DPI trend). All four methods demonstrate similar performance in the early and middle project stages. However, Earned Schedule (EAC(t)es) and Earned Duration Management (EAC(t)edm) methods clearly outperform the other two approaches during the final project stage. At the same time, very strange results for the Planned Value Method have been recorded once the planned completion time (9 weeks) has been reached and thus cannot be considered as a reliable predictor.

The following step in evaluation was inclusion of the stochastic risk-related factor. Additional extension of activity E was defined by BetaPERT distribution where optimistic extension was 0, most likely 0.5, and pessimistic 1 week (Figure 5). Monte Carlo simulation was used to evaluate the impact of potential extension of activity E on the performance of each of four forecasting methods (PVM, ED, ES, EDM), and both project scenarios (PF=1 and PF follows SPI/DPI trend).

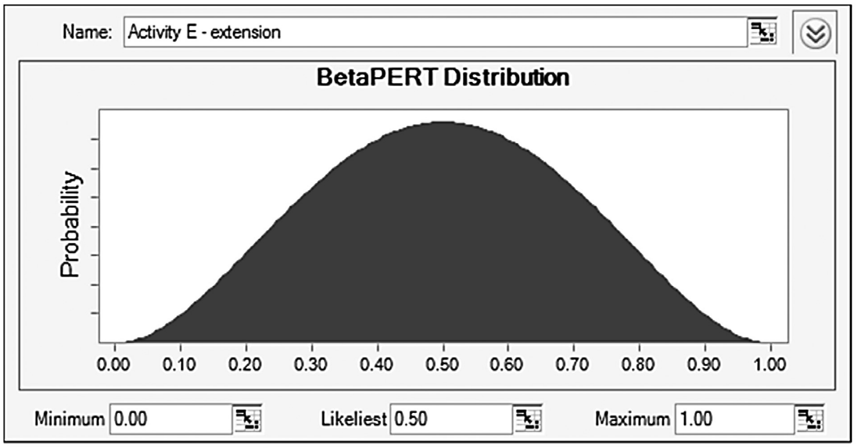


Figure 5: BetaPERT distribution for activity E

Results of the MAPE calculation were given in Table 4. Asterisks in the last column indicate the methods producing the smallest error. The PVM approach demonstrates the worst performance in both scenarios and highest forecast deviation (MAPE=0.1409 and 0.0959). The ED method scores as the second worse (MAPE=0.1238 and 0.0722). As expected, quantitative analysis shows that ES and EDM methods outperform the other two methods. Specifically, the ES method shows slightly better results with both scenarios (MAPE=0.1004 and 0.0502). MAPE values of EDM approach are very close to ES (0.1075 and 0.0539).

Table 4: MAPE calculation for different forecasting methods and scenarios

Forecasting method	Scenario	MAPE
PVM	PF=1	0.1409
ED	PF=1	0.1238
ES	PF=1	0.1004*
EDM	PF=1	0.1075
PVM	PF=SPI	0.0959
ED	PF=SPI	0.0722
ES	PF=SPI(t)	0.0502*
EDM	PF=DPI	0.0539

Generally, EDM proved to be a valid approach for project duration forecasting and represents a complement to the already widely accepted and recommended ES methodology. When it comes to the performance of ES and EDM as two most reliable methods, ES turned out to be more sensitive to changes, which is clearly illustrated by the curve change on week 7 on both graphs (Fig. 4). This can be attributed to the dynamics of ES and ED metrics and increments of earned value in monetary and time units. When it comes to the performance factor, all methods recorded much better results with the second scenario (PF= SPI, SPI(t), DPI), as a delay on activity C was followed by a delay and extension of activity E, without usual corrective actions performed by the management.

The results presented in this illustrative case confirmed some of the earlier findings, although there is still no clear consensus in the literature when it comes to the selection and the use of a single approach. In their real-life project studies, Vanhoucke and Vandevoorde (2007) and Batselier and Vanhoucke (2015a) stated that ES outperforms PV and EDM and therefore represents the most reliable metric. A detailed insight into the data used by this study and the obtained results leads to the conclusion that the performance of cost-based ES and time-based EDM largely depends on the dynamics of available inputs, which may differ.

The selection of the most reliable performance factor has been another important subject of earlier studies. While the simulation of Vanhoucke and Vandevoorde (2007) suggested the use of SPI(t) as the best performing factor, Batselier and Vanhoucke (2015b) found that PF = 1 shows the best performance in case of real-life project data. Another relevant research employed statistical forecasting and found that schedule forecasting from EVM data is improved when the PF = 1 (Lipke, 2017). However, some precaution was suggested when real data is used, and thus, some conclusions given in the recent literature should be further examined.

Unweighted methods (i.e. PF = 1) can partially account for possible corrective actions made by managers to improve lagging performance, and this can lead to more accurate forecast than those made with SPI, SPI(t) and DPI performance factor (Batselier & Vanhoucke, 2015a). The same authors concluded that the performance of the standard versions of SPI(t) based ES and DPI based EDM is strongly similar. Moreover, they provided a slight advantage to DPI-based EDM over SPI(t)-based ES (Batselier & Vanhoucke, 2015b). the illustrative project has showed that the selection of the weighted method (PF=SPI, SPI(t), DPI) provides more accurate results with the absence of managerial action that usually put project back on track. A slightly better performance is recorded with SPI(t)-based ES than DPI-based EDM.

Since validation of these approaches is often based on a limited number of historical cases, Willems and Vanhoucke (2015) suggested extending the research by using a larger and a more diverse historical dataset or by a well-designed simulation experiment. However, this kind of experiment is difficult to execute due to the nature of the different kinds of input data. Other improvements to existing techniques could include a shift from deterministic to probabilistic risk-related approaches (Acebes et al., 2015), introduction of other functions (besides time and cost) to evaluate performance more realistically, and development, implementation, and analysis of corrective action procedures, as previously described in section 2.3.

Conclusion

Although the EVM method has existed for more than five decades, when it comes to schedule management, scientific community has made an exceptional progress in the last fifteen years. In this paper, some of the most significant EVM based project duration methods were presented and evaluated on an illustrative project data. Generic formulas that forecast the project duration using different earned value metrics were given and further linked to two different forecasting models (i.e. performance factors).

The sample project illustrated the nature of the main contemporary approaches. It confirmed that the ES and EDM methods generate reliable results during the whole project lifespan and as such provide a solid ground for future improvements. It also confirmed that the forecasts obtained by the PVM and the ED methods become unreliable in the later stages of the project. However, when it comes to choosing between ES and EDM, there is still no clear consensus within the scientific community. A similar situation is with the selection of the appropriate PF, except that the slight preference is given to unweighted factors since they account for potential corrective management actions in real-life projects.

In the observed project ES in combination with weighted performance factor (PF= SPI(t)) provided better results over EDM and (PF=DPI), due to cost-based data that contributed to a more sensitive forecast and the absence of managerial action. This study has shown that a quest for one best approach (ES or EDM) and scenario (PF=1 or PF= SPI(t), DPI) may be in vain, as the performance of different approaches mainly depends on the dynamics of cost and time-based input data and the natural project uncertainty. It is affected not only by the risk we may capture by stochastic modelling, but by risks we were not able to define.

It is expected that future research will fully confirm that the selection of the right approach cannot be generalized. This kind of research should include a simulation with multiple early/late project scenarios and multiple stochastic inputs, where both methods will be tested with different performance metrics. However, this study has shown that this kind of experiment is very difficult to set-up, as it requires the use of different types and structures of inputs (cost and time-based).

When it comes to managerial implications, a general conclusion is that practitioners should focus on two best performing forecasting approaches (ES and EDM) and use the one that fits best to project needs. Further theoretical efforts should be oriented towards the development of easy-to-use software tools that can facilitate the acceptance and dissemination of findings. These should further encourage practitioners to test described improvements in practice and provide feedback for the future academic efforts.

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