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PROJECT DURATION FORECASTING:

A SIMULATION-BASED COMPARATIVE ASSESSMENT OF EARNED SCHEDULE METHOD AND EARNED DURATION MANAGEMENT

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Abstract: Since the ability to precisely forecast the project's total duration is of great importance for successful project management, a variety of approaches have been developed to address this issue over the last few decades. Recently, the Earned Duration Management (EDM) method has been proposed for monitoring schedule performance of a project and forecasting its total duration. It has been claimed that EDM method provides more accurate project duration forecasts compared with other EVM based approaches such as Earned Schedule Method (ESM). However, its potential and validity have not yet been adequately tried and tested. Therefore, in this paper, we extensively evaluate and compare the accuracy and reliability of EDM and ESM duration performance indicators to forecast the project's total duration on a vast variety of simulated projects with various network topology or structures through the Monte Carlo simulation technique. Moreover, the impact of correlation between time and cost profiles as well as the effect of degree of progression toward completion of the project on the forecasting accuracy of the above-mentioned methods are examined. The findings conclusively support Earned Duration Management as a preferred approach compared with Earned Schedule Method regardless of the network topology or completion stages of the project. Furthermore, forecasting accuracy of EDM vs. ESM considering correlated/uncorrelated profiles of time and cost also yields the overall dominance of EDM in the results.

1. INTRODUCTION

Earned Value Management (EVM) is a valuable and well-known tool used in the management and control of projects (Fleming and Koppelman, 2010). Monitoring the schedule/cost performance of projects and forecasting project total duration and cost are among the most important applications of EVM. The utility and reliability of EVM metrics to evaluate projects current cost performance and to forecast projects total cost has been endorsed and verified ever since the introduction of the technique in the 1960s (Batselier and Vanhoucke, 2017), and significant literature can be found which have proposed further developments to the traditional EVM in order to improve its cost component performance (Kim et al., 2011; Moslemi and Salehipour, 2011; Kim and Kwak, 2018). Despite this long validity in project cost management, EVM has not been as successful to monitor and manage the schedule of projects. It has been shown that EVM's schedule performance indicators represent an unreliable behavior and lose their predicting power toward the end of a project. Lipke (Lipke, 2003) developed the Earned Schedule Method(ESM) as an extension of traditional EVM to overcome these drawbacks. Although, ESM outperformed, all the other forecasting methods at the time(Vandevoorde and Vanhoucke, 2006) and became the most advisable, de facto method in representing and forecasting project schedule performance, it still keeps using monetary terms of Earned Value(EV) and planned Value(PV) as a proxy to measure schedule performance. Khamooshi and Golafshani (2014) criticized the use of EV for schedule and argued that there might be some correlations between duration and cost profiles throughout the project lifetime, but these profiles are not necessarily the same, thus performance measures that use a cost profile to offer a schedule performance measure will not be accurate. Therefore, they proposed the new method of Earned Duration Management(EDM) in which cost-free schedule performance indicators have been developed to measure schedule performance and to forecast project total duration. Although it is expected that EDM offers some improvements over ESM, assessing the forecasts obtained from EDM has not yet been adequately tested and verified. Therefore, in this paper, for the first time, an extensive simulation-based study has been conducted to compare the forecasting accuracy of EDM vs. ESM. Employing Monte Carlo simulation, we simulate project execution based on a large set of very diverse project network structures to objectively compare performance of EDM and ESM methods over multiple stages toward completion of project. The notion that cost and schedule profiles are not necessarily the same during the project lifetime was the main motive to introduce the new method of EDM. So, in this paper, we also study the accuracy of EDM duration forecasts in comparison with the ESM technique taking into account correlated/uncorrelated profiles of time and cost, which has not yet been considered in the literature.

The paper is structured as follows: Section 2 begins by presenting an overview of EVM, ESM, and EDM forecasting approaches. It is then continued by discussing the most important concepts that are used in this study and end with a comprehensive review of researches related to the ESM and EDM validity assessment. Then, our proposed research methodology is discussed in section 3. Subsequently, Section 4 is devoted to illustrating the results of our experiment. Finally, the conclusion and future research opportunities are presented in section 5.

2. Literature Review

2.1. Overview of Earned Value Management (EVM) and Earned Schedule Method (ESM)

The input parameters for the EVM method consist of three key metrics of Earned Value (EV), Planned Value (PV), and Actual Cost (AC). These cost-based metrics are used to calculate the performance measures of a project in progress and to make time and cost predictions about the future. In this paper, we focus only on the important metrics and formulas as summarized in **table 1**. For a comprehensive description of the main concepts, theories, and principles of EVM, interested readers are referred to the related Earned Value Management literature (Fleming and Koppelman, 2010; Anbari, 2003; and PMBOK, 2017).

Table 1. the description of EVM metrics and performance measures

	Metric	formula	Description
Key parameters	Planned value (PV)	---	The total budgeted cost of the work scheduled up to the reporting date
	Earned Value (EV)	---	the total budgeted cost of the work completed up to the reporting date
	Actual Cost (AC)	---	The total actual cost spent to complete the work up to the reporting date
Performance measures	Schedule variance (SV)	$SV = EV - PV$	$SV < 0$ *or* $SPI < 1$ project is behind schedule $SV = 0$ *or* $SPI = 1$ project is right on schedule $SV > 0$ *or* $SPI > 1$ project is ahead of schedule
	Schedule Performance Index (SPI)	$SPI = EV/PV$	
	Cost Variance (CV)	$CV = EV - AC$	$CV < 0$ *or* $CPI < 1$ project is over budget $CV = 0$ *or* $CPI = 1$ project is right on budget $CV > 0$ *or* $CPI > 1$ project is ahead of budget
	Cost Performance Index (CPI)	$CPI = EV/AC$	

Lipke (2003) criticized the EVM schedule performance metrics, SV and SPI, since they provide unreliable time forecasts toward the end of the project. Therefore, he developed Earned Schedule Method (ESM) as an extension of traditional EVM in which a new time performance metric (SPI(t)) was introduced based on the ES concept. Earned Schedule (ES) identifies the time at which the amount of EV accrued should have been occurred (Lipke, 2009) and it is mathematically calculated as follows:

$$\text{Find } t \text{ such that } EV \geq PV_t \text{ and } EV < PV_{t+1} \qquad (1)$$
$$ES(t) = t + (EV - PV_t)/(PV_{t+1} - PV_t)$$

Where EV is the Earned Value at the Actual Duration AD, 〖PV〗_t is the Planned Value at the time instant t. Using the ES concept, the EVM schedule performance metrics reformulated as follows:

$$SV(t) = ES - AD \qquad (2)$$
$$SPI(t) = ES(t)/AD$$

Where AD is used to refer to the Actual Duration. **Figure 1** illustrates the concept of ESM vs. EVM and the associated metrics.

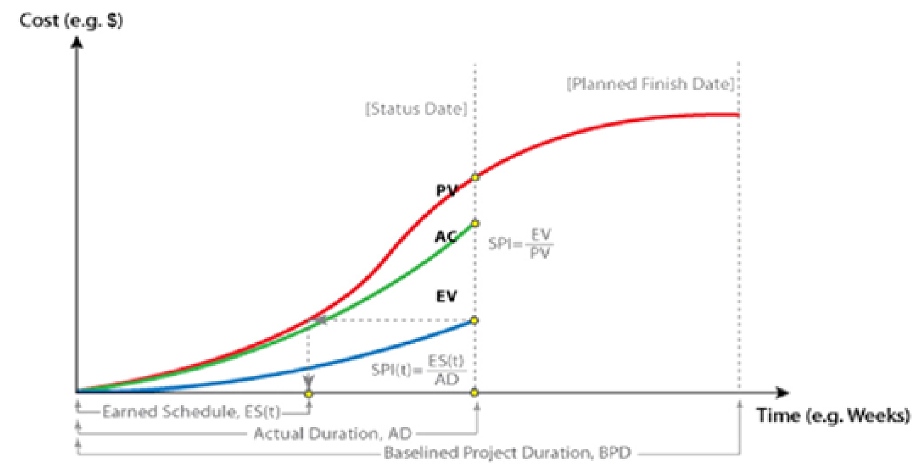

Figure 1. Conceptual EVM and ES graph (Khamooshi and Golafshani, 2014)

2.2. Overview of Earned Duration Management (EDM)

Although ESM and its Schedule Performance Index (SPI(t)) offer improvements over EVM and SPI, they still use monetary terms of Planned Value (PV) and Earned Value (EV) to measure schedule performance. To tackle this drawback, Khamooshi and Golafshani (2014) have developed Earned Duration Management (EDM), in which schedule and cost performance measures are completely decoupled. More specifically, EDM provides three new concepts as alternatives to EVM key metrics: Total Planned Duration (TPD), Total Earned Duration (TED), and Total Actual Duration (TAD) as duration-based equivalents of the PV, EV, and AC respectively. It is to be noted that at the activity level PDi, EDi and ADi are counterparts of PVi, EVi and ACi for the activity IIn the ESM method, the EV projection on PV curve at the Actual Duration represents the Earned Schedule(ES(t)), in the EDM method, ES(t) has been replaced by Earned Duration (ED(t)) which is similarly calculated by projecting the TED on the TPD curve at the time instant t. ED(t) determines the time at which the amount of TED occurred was planned to occur and it is calculated according to the following formula:

Find t such that $TED \geq TPD_t$ and $TED < TPD_{t+1}$

$$ED(t) = t + \frac{TED - TPD_t}{TPD_{t+1} - TPD_t} \quad (3)$$

Using ED(t) concept and the Key metrics, EDM offers a completely time-based measure named Duration Performance Index (DPI) to monitor and forecast the schedule performance of a project. Supplementary explanations and formulas are represented in **table 2**. Finally, Earned Duration Management substitutes the cost-time EVM graph (**figure 1**) for a new time-time EDM graph (**figure 2**), in which the y-axis represents the cumulative duration of planned activities and the x-axis shows the time horizon of the project between its start and finish or the critical path.

Table 2. the description of EDM metrics

	metric	formula	Description
Key parameters	Total Planned Duration (TPD)	$TPD = \sum_{i=1}^{n} PD_i$	summation of Planned Duration (PD) for all the planned activities at the Actual Time (AT) according to the baseline schedule
	Total Earned Duration (TED)	$TED = \sum_{i=1}^{n} ED_i$	summation of Earned Duration (ED) for all the in-progress and completed activities at the Actual Time (AT)
	Total Actual Duration (TAD)	$TAD = \sum_{i=1}^{n} AD_i$	summation of Actual Duration (AD) for all the in-progress and completed activities at the Actual Time (AT)
Performance measures	Duration Performance Index (DPI)	$DPI = \frac{ED(t)}{AT}$	$DPI < 1$: project is behind schedule $DPI = 1$: project is right on schedule $DPI > 1$: project is behind schedule

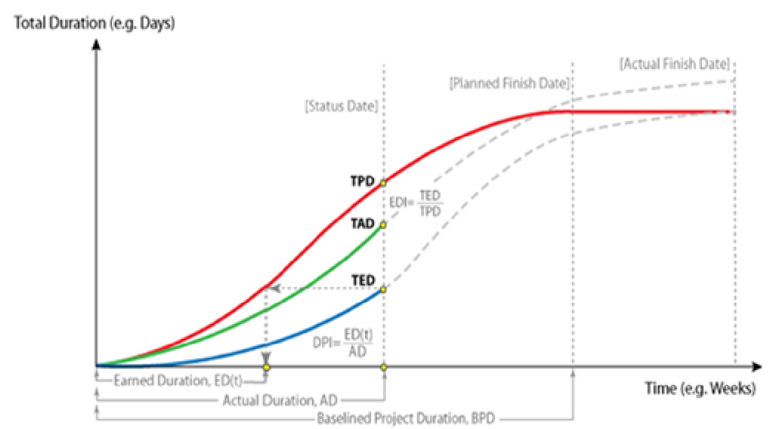

Figure 2. Conceptual EDM graph (Khamooshi and Golafshani, 2014)

2.3. Forecasting Project Duration

The value of key metrics must be collected at regular time intervals or review periods at which the status of the project in progress is monitored and controlled (Vanhoucke, 2014). These key metrics are used to calculate project performance measures based on which the total duration of a project is forecasted.

To obtain duration forecasts from the ESM method, we apply the following formula, which has been proposed by Henderson (Henderson, 2004):

$$EAC(t) = AD + \frac{(BPD - ES(t))}{PF} \quad (5)$$

Where PF is the performance Factor representing the expected schedule performance in the future. A wide set of possible performance Factors for ESM project duration forecasting have been developed and evaluated in the literature (Vanhoucke and Vandevoorde, 2007; Vanhoucke, 2009; Batselier and Vanhoucke, 2015a), but since our goal is to compare the primary forms of Earned Schedule and Earned Duration methods, we apply the ES-based Schedule Performance Index, SPI(t), as the Performance Factor in the project duration forecasting formula.

Analogously, inspired by Khamooshi and Abdi (2017), the formula to determine the final project duration forecast using the EDM method is defined as:

$$EDAC(t) = AD + \frac{BPD - ED(t)}{PF} \quad (6)$$

With AD the Actual Duration (at the status date), BPD the Baseline Project Duration, and ED(t) the Earned Duration at the time instant t. According to the above-mentioned discussion, we assume the ED-based Duration Performance Index (DPI) as the Performance Factor in the formula, which implies that the future duration performance will be equal to the current duration performance.

2.4. Project Network Topology Structure

Topological structure or the exact shape of a project network describes the relationship between project activities and their corresponding precedence relations (Vanhoucke, 2012). The performance of methods recommended for managing projects, mostly heuristics, particularly in areas of project scheduling, risk analysis and, resource allocation, heavily depends on the topological features of the project network (Valadares Tavares et al., 2002). In this regard, Tavares et al. (Valadares Tavares et al., 1999) proposed a set of indicators (I_1,I_2,I_3,I_4) to categorize the different kinds of project networks. It has been proven in the literature that among these indicators the topology network characteristic I_2(i.e. serial/parallel indicator) highly affects the project duration forecasting accuracy obtained from the EVM and ESM methodologies (Vanhoucke and Vandevoorde, 2007; Vanhoucke, 2012). The serial/ parallel indicator (SP) describes the closeness of a project network to a complete parallel (SP=0) or a perfect serial network (SP=1) and it is calculated by the following formula:

$$SP = \frac{m-1}{n-1} \quad (4)$$

With m the maximum number of subsequent activities in the network and n the total number of network activities(Vanhoucke et al., 2008). In this paper, we incorporate and extend the concept of serial/parallel indicator to the EDM method and answer the following questions:

- How Can project network topology affect the forecasting accuracy of the Earned Duration Management?
- How EDM performs in comparison with the ESM technique considering different network topology structures?
- Does EDM perfromance will be affected as a function of project progression?

2.5. The Correlation between Time and Cost

As explained in the introduction, the issue of correlation between cost and time profiles was the main driver to introduce EDM. Using cost-based data (PV, EV) to measure project Schedule Performance Indexes (SPI,SPI(t)) implies that correlated profiles of time and cost are the default assumption of both EVM and ESM methodologies. Although this assumption is valid in some projects, it is not always the case. Using a simple example, Khamooshi and Golafshani (2014) have shown that a high-cost and low-duration activity like procurement can dramatically set time and cost profiles apart at the time and invalidate SPI(t) to an extent that it performs even worse than SPI. The higher the disparity between time and cost of a project, the more inaccurate the ESM schedule performance indicator (Khamooshi and Golafshani, 2014). To draw a comprehensive comparison between the two methods of ESM and EDM, it is crucial to investigate the impact of time and cost correlation on their forecasting accuracy. Therefore, in this paper, for the first time, this issue is adequately checked out on a wide set of artificially generated projects.

2.6. Previous research in ESM duration forecasting

Within a year of introducing the ESM technique, Henderson (2003) was the first researcher who has verified the ES concept and its derivative indicators using a portfolio of six projects. Afterward, multiple studies have been dedicated to investigating the potential and validity of the ESM methodology in various ways. For instance, Vanhoucke and Vandevoorde (2007) have conducted a simulation study to examine the ESM forecasting accuracy in comparison with EVM and other methods that were widely used at the time. They have also considered the impact of network structure and completion stages on the obtained forecasting accuracy from the ESM method. Then, in a series of studies, Vanhoucke, in collaboration with other researchers has examined the forecasting potential of ESM considering early or late projects(Vanhoucke and Vandevoorde, 2008), different topology structures (Vanhoucke and Vandevoorde, 2009), and various Performance Factors (Batselier and Vanhoucke, 2015a) in both real and simulated projects. Lipke (Lipke, 2009) used the performance data from 16 projects to assess the capabilities of the various forecasting methods, including the ESM technique at different completion ranges. Some other researchers have discussed the effectiveness of ESM application in different industries and disciplines from construction to hydroelectric power production projects (Lipke and Henderson, 2006; Hecht, 2007; Rujirayanyong, 2009; Tzaveas et al., 2010; Urgilés et al., 2019). More recently, Cho and Lim (Cho and Lim, 2018) have applied EVM and ESM to 32 defense research and development project, and the results confirmed the dominance and supremacy of ESM over EVM. The common result of these studies was the dominance and supremacy of ESM in forecasting project total duration.

2.7. Previous research in EDM duration forecasting

Assessment of the performance and reliability of the duration-based EDM method compared with prior recommended techniques seems well justified. In this regard, Batselier and Vanhoucke, (2015b) used empirical data of 23 projects to compare EDM with ESM and concluded that EDM performs slightly better than ESM and it certainly proves to be a valid methodology for project duration forecasting. Khamooshi and Abdi (2016) tested the forecasting accuracy of EDM applied to a dataset of 19 real-life projects at multiple stages of the project completion date. The authors reported that duration-based performance measure is a better indicator for predicting the duration of a project. Moreover, they merged the methods with the exponential smoothing forecasting technique to enhance the accuracy of EDM project duration forecasting. A more precise comparison has been conducted by André et al., (2019) in which the reliability of EDM and ESM methods have been investigated on 57 projects of various sectors considering project structure characteristics. The result was the same, the EDM forecasting method yields better project duration forecasts. They've also developed composite factors combining schedule performance and schedule adherence in order to improve the accuracy of EDM project duration forecasts. Ballesteros-pérez et al., (2019) compared 26 deterministic project duration forecasting techniques including EDM and ESM, through both simulated and real projects. Votto et al., (2020) used EDM duration-based indicators in a statistical project control method to monitor the performance of a real EPC project, and the obtained results showed that the DPI control chart generally exhibits better performance rather than traditional SPI(t) index. In addition, further studies have addressed the development of EDM to improve its application and efficiency (Mortaji et al., 2017; Wood, 2018; San Juan and Polancos, 2019; Yousefi et al., 2019).

3. Research Methodology

As explained above the main objective of this paper is bipartite. First, the effect of correlation between cost and time profiles will be investigated on the forecasting accuracy obtained from EDM in comparison with the ESM approach. Second, we aim to conduct a comprehensive assessment of EDM time-based indicators to forecast project duration considering various simulated network topologies at different project completion stages and compare the results to the ESM methodology. The details of our approach and methodology for conducting this research is presented in the following subsections.

3.1. Simulated Project Database

In this paper, we use simulated projects to assess and evaluate the forecasting accuracy of the EDM vs. ESM method, an approach which has been adopted by many previous researchers(Elshaer, 2013; Lipke, 2016; Batselier and Vanhoucke, 2017). Real projects are limited in terms of complexity, diversity, size, and even network topology whereas simulation provides the opportunity to generate a large set of projects with various characteristics based on which a more comprehensive comparison can be made. The use of simulated projects as well as real life projects are reported in the literature. Batselier and Vanhoucke (Batselier and Vanhoucke, 2015a) argue that simulation results can be regarded as support for real life project forecasting results.

Our simulated database contains 1200 activity-on-node generated networks. Unlike simulated projects dataset provided by the University of Ghent's Operations Research & Scheduling Research Group (https://bit.ly/2OYl34Q) and used in multiple studies (Elshaer, 2013; Ballesteros-pérez et al., 2019)each project network in our data set consists of 100 activities instead of 30 activities to make our simulated networks much closer to the real-life projects. These projects are generated by the RanGen2 project network generator tool (Demeulemeester et al., 2003; Vanhoucke et al., 2008) under controlled network structures. More precisely, project networks are generated within the following SP categories proposed by Batselier and Vanhoucke (Batselier and Vanhoucke, 2015a) to be separated based on their topological structure:

$0\% \leq SP < 40\%$ | Parallel projects
$40\% \leq SP \leq 60\%$ | Serial/parallel projects
$60\% < SP \leq 100\%$ | Serial projects

After generating project networks with pre-determined topology structures, baseline schedules are established by assigning random numbers obtained from a uniform distribution to each activity duration and cost. At this time, PV in the ESM approach and TPD in the EDM method can be calculated at any status date, which is assumed monthly intervals.

To simulate project execution, the actual duration and cost of activities are required. Actual activity durations are simulated using a triangular distribution tailed to the right that leads to the activity delays. The rationale behind this assumption is the fact that in most real-life projects, activities normally end up late or, at best, on schedule. Actual activity costs are assumed to vary uniformly with the corresponding activity durations. Then, the actual costs and durations are used as inputs for the Monte-Carlo simulation method to simulate project execution. To draw a general and objective conclusion, the simulation procedure was run 100 times for every project in our database by using the MATLAB programming language. As a result, the outputs of the simulation are key parameters of EV and AC for the ESM technique and the corresponding TED and TAD in the EDM method. Using these key parameters, the ESM and EDM performance measures are calculated based on which the project total duration is forecasted using formulas mentioned in section 2.3. It is worth noting that the simulation approach applied in this paper is inspired by Vanhoucke (Vanhoucke, 2012).

3.2. Assessment of time and cost correlation

In section 2.5, we have extensively explained the correlation between time and cost and its possible relation with the forecasting accuracy of the considered methods. To examine the impact of correlated and uncorrelated time and cost profiles on the EDM and ESM forecasting accuracy, the randomly generated numbers for activity durations and costs must be controlled as follows. Activity durations are obtained from a uniform distribution, as illustrated in section 3.1. Activity costs are generated by an increasing function (e.g., the longer duration the activity takes, the more it costs) or a decreasing function (e.g., the longer duration the activity takes, the less it costs) at different rates to develop correlated and uncorrelated time and cost profiles respectively. Therefore, we generate two separate sets of projects, one with correlated input data and another set with decoupling time and cost. Finally, the controlled constructed baseline schedules go through the simulation steps as mentioned in the previous section.

3.3. Forecasting Accuracy and Reliability Evaluation:

In this paper, we use the following two methods for comparing the forecasting accuracy of the methods under review (ESM and EDM). First, inspired by several studies on the ESM forecasting Accuracy (Elshaer, 2013; Batselier and Vanhoucke, 2015a; Lipke, 2017), we calculate the widely used criterion of Mean Absolute Percentage Error (MAPE) to determine the forecasting accuracy as follows:

$$MAPE = \frac{1}{n}\left(\sum_{t=1}^{n}\left|\frac{TAD - EDAC(t)^t}{TAD}\right|\right) \qquad (7)$$

Where TAD is the project Total Actual Duration, EDAC(t)t denotes the Estimated Duration at Completion at the status date t and n is the number of reporting periods or status dates. The lower MAPE indicates a better forecasting method or more accuracy. Second, as a measure of the reliability of the method, we calculate the proportion of times each method performs better by counting the number of times each method generates a lower percentage error.

According to Covach et al., (1981), the accuracy of forecasts depends on the completion stages of the project; therefore, in this paper, we measure the forecasting accuracy of ESM and EDM using the two above-mentioned methods at both overall project lifespan and different stages of project progression (early, middle, and late). To conduct this multi-stage experiment and analysis, following Batselier and Vanhoucke, (2015b) three categories are defined according to the percent complete(PC) ranges:

	Project completion percentage
Early	0% ≤ PC < 30%
Middle	30% < PC < 70%
Late	70% ≤ PC ≤ 100%

4. Results and discussion

In this section, our findings and results are presented and discussed. While the following results are based on findings from a set of simulated projects, it must be noted that, as we have tested two philosophically different approaches, the same results could easily be replicated for real life projects. This section is divided into 4 subsections.

The effect of time and cost correlation on the forecasting accuracy of EDM and ESM methods is discussed in subsection 4.1. The other three subsections provide an evaluation of overall forecasting accuracy (4.2), the accuracy of ESM and EDM at various stages of completion, and the impact of project network topology on forecasting accuracy of EDM vs. ESM (subsections 4.3 and 4.4 respectively).

4.1. Influence of Cost and Time Correlation on Forecasting Accuracy

In this section, using the previously described methodology, we attempt to examine the effect of correlation between cost and time on the efficiency and accuracy of project duration forecasts resulted from using EDM vs. ESM performance indicators. To achieve this goal, we have applied the simulation approach to the two sets of projects with correlated and uncorrelated time/ cost profiles and measured forecasting accuracy. The average MAPE values of the considered methods over the whole project lifespan are presented in **table 3**. It can be realized that when cost and time profiles are correlated, the EDM performs only slightly better than the ESM technique (1% difference in MAPE). On the contrary, disparate, or decoupled time and cost trends strongly decrease the forecasting accuracy of ESM (MAPE of 17.5%), while the cost-independent EDM results remain unchanged. For a deeper illustration, the analysis of time and cost correlation's effect on forecasting accuracy is applied considering different topology structures along the project's completion stages. The MAPE (%) values reported in **table 4** are calculated from the EDM project duration forecasts; moreover, **tables 5 and 6** summarize the MAPE (%) of the ESM duration forecasting for projects with correlated and uncorrelated time and cost profiles respectively. By comparing the EDM results with those of the ESM approach, it can be concluded that cost and time correlation obviously affect the forecasting accuracy of project duration as explained above regardless of topology structure or project's completion stages.

Since the EDM method uses cost decoupled indicators, it was expected that its forecasting accuracy is not affected by time and cost correlation, which is confirmed by our assessment. More precisely, no matter how different time and cost profiles are, it will not affect the accuracy obtained from the EDM method. However, the ESM method is valid as long as time and cost profiles are the same. The predictive accuracy of ESM is called into question once cost and time profiles diverge.

Table3. Average of MAPE for 1200 projects for each performance index

Method	EDM-DPI	ESM Correlated time and cost	ESM Uncorrelated time and cost
MAPE%	10.48	11.10	17.50

Table4. EDM-DPI Average of MAPE for 1200 projects

		overall	Early	middle	late
EDM-DPI	0.1<=SP<0.4	13.625	31.276	10.316	6.137
	0.4<=SP<=0.6	11.078	29.256	5.626	2.979
	0.6<SP<=0.9	6.7518	18.380	2.800	1.5111

Table5. ESM-SPI(t) Average of MAPE for 1200 projects (correlated time and cost)

		overall	early	middle	Late
ESM-SPI(t) (correlated time and cost profiles)	0.1<=SP<0.4	13.754	32.580	10.038	6.060
	0.4<=SP<=0.6	11.605	30.647	5.972	3.038
	0.6<SP<=0.9	7.950	21.654	3.277	1.782

Table6. ESM-SPI(t) Average of MAPE for 1200 projects (uncorrelated time and cost)

		overall	early	middle	late
ESM-SPI(t) (uncorrelated time and cost profiles)	0.1<=SP<0.4	20.946	53.825	14.665	7.987
	0.4<=SP<=0.6	17.679	47.263	8.852	4.386
	0.6<SP<=0.9	13.896	37.651	5.932	3.031

4.2. Overall forecasting accuracy

This section presents our findings on the overall forecasting accuracy of methods EDM-DPI and ESM-SPI(t) for all the projects in our database. As discussed before, the results of each method are evaluated by calculating the average MAPE for all 1200 simulated projects, and the number of times that the method performs the best (the least error) as a percentage of all the attempts (1200). These results are presented in **table 7**. Based on MAPE, the most accurate and reliable method for project duration forecasting is EDM-DPI acquiring the lowest MAPE of 10.48%. Considering the number of times each method performs the best, once again the dominance of EDM-DPI is demonstrated. As it is shown in table 7, when DPI is used as a performance factor, the highest forecasting accuracy and reliability is achieved in 86.75% of all simulated cases, whereas ESM-SPI(t) performs the best only in 13.25% of all 1200 projects in the database.

The outcome that EDM-DPI outperforms the most recently recommended approach e.g. ESM was not unexpected since DPI as a time-based metric eliminates the impact of cost on-time performance measures and subsequently on project duration forecasting. Moreover, the dominance of EDM-DPI over ESM-SPI(t) has been concluded in the study of Batselier and Vanhoucke (Batselier and Vanhoucke, 2015b) by applying the method to forecast the duration of 23 real-life projects. As mentioned in section 3.1, our simulation-based assessment can be regarded as a support to such studies.

Table7. Overall forecasting accuracy for 1200 projects

	EDM-DPI	ESM-SPI(t)
MAPE%	10.485	14.008
Rank%	86.75	13.25

4.3. Impact of Project Completion stages on forecasting accuracy

Besides overall forecasting accuracy, we are also interested in the evaluation of forecasting accuracy along the completion stages of the project as discussed in section 3.3. The performance of duration forecasting methods over the project lifespan including three stages, namely early, middle, and late, is shown in **table 8**.

Considering the outcome of our analysis and the results of each stage, has revealed that the forecasting accuracy improves as the project moves toward later stages for all methods used. This is in accordance with studies that investigate ESM duration forecasting over different completion stages (Vanhoucke and Vandevoorde, 2007; Vanhoucke, 2009). Comparing EDM-DPI and ESM-SPI(t), we can observe that EDM-DPI yields more accurate forecasts than the results obtained from the ESM approach irrespective of project completion stages. Therefore, the dominance of EDM becomes apparent once more.

While the performance of EDM-DPI along all completion stages of the project is remarkably important, Teicholz, (1994), Kim, (2007), and Liana, (2017) pointed out that project managers prefer getting accurate forecasts in the early stages of the project in order to make effective management decisions. **Figure 3** reveals that in the middle and late stages EDM-DPI performs slightly better than ESM-SPI(t) but there is a major accuracy difference between the two methods in the early stage. This indicates that EDM-DPI has the potential to act as a better early warning signal to take timely preventive and corrective actions that are crucial to project control and ultimately project success.

Table8. Average of MAPE for 1200 projects over project

	early	Middle	late
EDM-DPI	26.31	6.25	3.54
ESM-SPI(t)	35.88	8.09	4.46

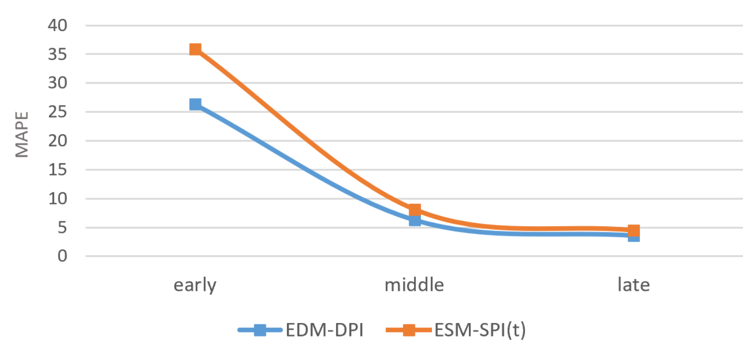

Figure 3. Average of MAPE for 1200 project considering project completion

4.4. Topological Structure and Forecasting Accuracy

Our findings of the impact of network topological structure on the forecasting capability of the two methods of EDM and ESM are presented in this subsection. The results obtained from our simulation-based study convincingly reply to the questions presented in section 2.4 as follows. With respect to the MAPE results shown in **table 9** and **figure 4**, it can be verified that serial/ parallel indicator (SP), which measures the closeness of a project network to a serial (S) or parallel (P) network, evidently influences forecasting accuracy of both EDM-DPI and ESM-SPI(t). The duration forecasting accuracy increases for projects with more serial activities (i.e., SP closer to 1). It is noteworthy, this result has initially concluded by Tavares (Tavares et al., 1999) and thereafter validated by studies in the literature that evaluated time forecasting approaches including ESM based on both simulated and real project database (Vanhoucke and Vandevoorde, 2007; Colin and Vanhoucke, 2015; Lipke, 2015).

Table 9. MAPE results

	EDM-DPI				ESM-SPI(t)			
	overall	early	middle	Late	overall	early	middle	late
0.1<=SP<0.4	13.625	31.276	10.316	6.137	17.059	40.752	12.642	7.282
0.4<=SP<=0.6	11.078	29.256	5.626	2.979	14.298	38.070	7.130	3.696
0.6<SP<=0.9	6.7518	18.380	2.800	1.5111	10.644	28.829	4.524	2.374

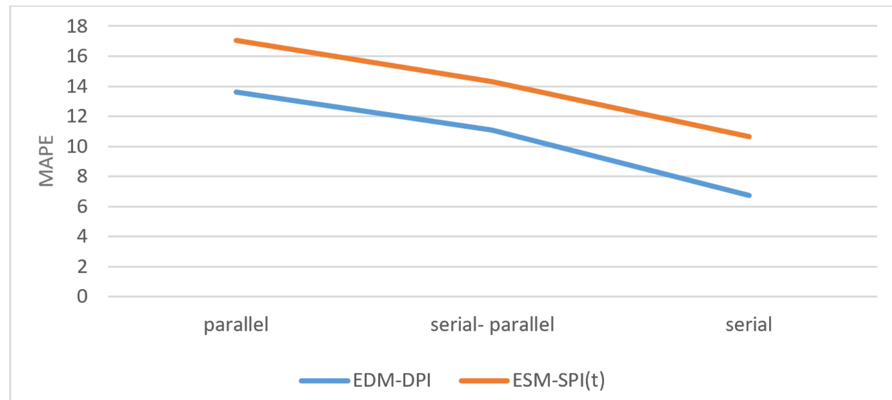

Figure 4. Average of MAPE for 1200 projects considering the topological

The current study shows that the serial/parallel (SP) indicator affects the forecasting accuracy of EDM like the ESM method. They both perform better in serial networks. This result can help practitioners and researchers to correctly use EDM in more serial networks and seek some additional techniques when the network topology is closer to parallel, as Lipke (Lipke, 2012) applied a possible approach for resolving the problem of ESM low performance in parallel networks.

Referring to **figure 4**, we could easily compare the EDM and ESM forecasting accuracy regarding different network topological structures. The MAPE of EDM-DPI starts with 13.62% for more parallel networks (i.e., SP ranging between 0.1 and 0.4), then decreases with the growing level of seriality and eventually ends in 6.75% for more serial network structures (ranging between 0.6 and 0.9), which are substantially better than ESM-SPI(t) performance.

5. Conclusions and Future Research

The uncertainty associated with projects as a function of project characteristics and their environment (estimation risk, operations risks, strategic risks, safety risks) is part and parcel of project and project management. As such any improvement in project outcome prediction and control can assist managers in taking appropriate corrective and preventive actions to secure more successful delivery of projects. Hence, more accurate cost and duration forecasts are essential to successful project management. In the PM literature, It has been repeatedly demonstrated that EVM can predict highly accurate cost forecasts but fails to address project schedule performance and provide a reliable estimate of project total duration. Using cost as a proxy for measuring the duration performance of the project has been identified as the main flaw of the EVM and its derivatives (e.g., Earned Schedule Method). EDM, the newly developed approach, presents cost-free indicators to measure the progress and monitor the performance of a project schedule.

In this paper, we have focused on the EDM performance vs. ESM to forecast the project total duration based on an extensive simulated set of projects. First, we have investigated the effect of correlation between time and cost profiles on the forecasting accuracy of the considered methods. Irrespective of time and cost correlation, EDM has produced more accurate forecasts; whereas, ESM was valid as long as time and cost profiles were highly correlated. Second, we have performed an extensive assessment of the overall forecasting reliability as well as stage-wise forecasting accuracy of EDM vs. ESM using 1200 simulated projects with different network topology structures. The experiment has provided enough evidence to support the notion that the EDM-DPI approach outperforms the ESM approach on all the accounts. More precisely, EDM did perform better when used over the overall project lifespan and different stages toward the project completion. Moreover, the impact of project topological structure on the forecasting accuracy obtained from EDM and ESM has been analyzed and assessed. It has shown that the EDM method forecasting accuracy increases with the growing level of project network seriality similar to the ESM method. This should be expected as a serial topology reduces the chance of change in the critical path and multicritical path issue. It is to be noted that real-life projects are almost always leaned toward more parallel topology. Hence, complementary approaches to improve EDM forecasting accuracy in parallel networks could be conducted as a future research path. Also it is to be noted that we have only considered late projects in this paper; therefore, a more extensive study simulating different execution scenarios(early or on-schedule projects) can also be considered in future researches.

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PROJECT DURATION FORECASTING:

A SIMULATION-BASED COMPARATIVE ASSESSMENT OF EARNED SCHEDULE METHOD AND EARNED DURATION MANAGEMENT