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Original
Integrating risk in project cost forecasting / De Marco, A.; Narbaev, T.; Rafele, C.; Cagliano, A. C.. - In: ...SUMMER SCHOOL FRANCESCO TURCO. PROCEEDINGS. - ISSN 2283-8996. - STAMPA. - 2017(2017), pp. 117-122. ((Intervento presentato al convegno 22nd Summer School "Francesco Turco" - Industrial Systems Engineering 2017 tenutosi a Mondello Palace Hotel, Viale Principe di Scalea, ita nel 2017.

Availability:
This version is available at: 11583/2697846 since: 2018-01-20T19:57:14Z

Publisher:
AIDI - Italian Association of Industrial Operations Professors

Published
DOI:

Integrating Risk in Project Cost Forecasting

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Abstract: Estimating duration and cost at completion based on Earned Value Management (EVM) data and managing risk contingency accounts in ongoing projects are typically treated by both scholars and practitioners as separate processes of project monitoring. However, project risk is claimed to significantly impact on project schedule and cost performance. As an attempt to combine these two management areas, the paper illustrates a methodology for improved schedule-based cost estimates at completion with the added nonlinear profile of risk contingency cost consumption. In particular, the model builds upon a Gompertz S-curve shaped cost profile equation. The model is applied to a sample of real project datasets. Its estimate accuracy and stability are tested at various early, middle, and late stages of project development. The proposed schedule-cost-risk estimate methodology proves to be a viable and effective tool to compute refined estimates at completion of complex projects involving formal management of contingency escrow accounts. The theoretical contribution is about creating a stronger connection between EVM and risk contingency management theories. Practical implications are inherent with the ability of the methodology to integrate cost contingency (CC) management into cost and schedule monitoring processes.

Keywords: Project Management, Earned Value Management, Risk Management, Estimates At Completion

1. Introduction

Based on the Earned Value Management (EVM) methodology it is possible to compute schedule and cost performance indices (SPI and CPI) and to predict final time and cost estimates at completion of a project (De Marco et al., 2009). Studies on the reliability of time and cost estimates based on such indices are subject to some limitations (Narbaev and De Marco, 2013). First, traditional index-based EVM forecasts just rely on past project performance, which may not always reflect the project future behaviour and potential uncertainties that may impact on cost performance (Christensen et al., 1995). Second, due to inaccurate project progress measurement, the method can lead to unreliable predictions, especially in the early stages of the project execution (Kim and Reinschmidt, 2011). Third, EVM-based estimates do not consider the process of managing risk as an intrinsic factor of project performance and fail to integrate the dynamics of consumption of the cost contingency (CC) during project development (Ford, 2002; De Marco et al., 2016a).

Although techniques are available to overcome some of these limitations, there is still the need for methodologies able to incorporate cost estimates at completion into CC management practices. In fact, the processes of estimating cost at completion and managing risk contingencies are often used separately and are not integrated (Xie et al., 2012).

These considerations suggested to develop a cost estimate at completion (CEAC) methodology that integrates CC management. In particular, building on the works carried out by Narbaev and De Marco (2013; 2014), we present a methodology for improved CEAC of ongoing projects that considers the consumption of the CC budget as a factor of final project total cost.

In this paper we first explore pertinent literature. Second, we present the methodology. Then, we discuss the results obtained by the application of the proposed forecasting method to eight construction projects. Finally, we summarize the main conclusions and highlight future research directions.

2. Review of Relevant Literature

Based on index-based EVM, linear CEACs can be obtained with several forecasting methods (PMI, 2013). Common formulations are founded on the assumption that past performance is a predictor of future performance so that remaining cost to complete is linearly adjusted by past performance (Anbari, 2003). Under index-based linear assumptions, CEAC is defined as the ratio of the original budget at completion (BAC), to the CPI or to a combination of CPI and SPI. By combining CPI and SPI it is assumed that the final cost is additionally influenced by schedule performance. In particular, CPI is defined as the ratio of Earned Value (EV) to Actual Value (AV) and SPI as EV to Planned Value (PV), both expressed in monetary units. However, the usage of SPI computed in, e.g., dollar amounts, fails to predict late estimates as it tends to one as the project tends to completion, i.e.: EV tends to converge to PV. Therefore, Lipke (2003) proposed the Earned Schedule (ES) method to calculate SPI and express the index in time units. ES is a measure of schedule performance expressed in time units and is used to compute SPI(*t*) defined as ES over the actual time of measurement. Comparative studies showed that the ES-based linear CEAC estimates are more accurate and reliable than the ones based on EV expressed in monetary units (Kim et al., 2003; Cioffi, 2005; Lipke et al., 2009).

However, these methods can result unreliable especially in early estimates because of few available EVM data at the beginning of the project. In addition, such estimates are considered as just dependent on past performance, which may fail to consider variations due to future possible risk (Fleming and Koppelman, 2006; Kim and Reinschmidt, 2011).

To overcome such limitations, some methodologies have been proposing to use linear or non-linear regression models in order to provide more reliable CEAC formulae. These regression models have been refined in order to fit to the S-curves of cumulative cost since the early stages of a project (Cioffi, 2005; Lipke et al., 2009). As part of this stream of research, cost forecasts proved more reliable when integrating EVM into regression-based S-curve fitting (Narbaev and De Marco, 2013). Also, some authors have been integrating simulation methods into EVM to better capture the influence of risk as a determinant of future project performance (Vanhoucke, 2011; Pajares-López and Paredes, 2011; Acebes et al., 2015). However, most of the studies with simulations focus primarily on schedule performance and time estimates rather than on CEACs.

With this regard only a few works consider CC management as an integral and important part of project monitoring (De Marco et al., 2016b; Narbaev and De Marco, 2017). Risk contingencies should be not only properly calculated and assigned in the budget estimation process, but also wisely consumed and controlled during the project execution (Barraza and Bueno, 2007). With this regard, Cioffi and Khamooshi (2009) developed a methodology to estimate the total potential impact to allow project managers set aside corresponding contingency funds. Xie et al. (2012) presented a method for project CC forecasting and updating based on value at risk during the project execution. However, limited literature explores how risk contingency is managed during the project and how it impacts on project performance and cost forecasting (De Marco et al., 2016a). This paper is aimed at filling this research gap by exploring the integration of CEAC methodologies into CC management practices. In particular, it proposes a mixed index-regression model adjusted with estimated CC. Such a model promises accurate and reliable CEACs.

3. Contingency-Adjusted CEAC Formula

The new proposed CEAC methodology takes into account the influences of both the progress performance and CC utilization during the execution of a project. It is based on the model proposed by Narbaev and De Marco (2014), referred hereafter to as the base model. With the purpose of improving and extending CEAC methodologies, the base model uses a Gompertz growth model (GGM) and incorporates the ES-based estimate of the duration of the project. A generic model of GGM is given in Equation 1 (Narbaev and De Marco, 2014).

The application of the base model requires the determination of the α, β and γ parameters of the GGM estimated using non-linear regression analyses. The α parameter is the future value asymptote of the model that represents the final cost (which is never attained) as time x tends to infinity (Seber and Wild, 1989), the β parameter is the y-intercept indicating an initial budget size, and γ is a scale parameter that governs the cost growth rate. Then, CEAC can be calculated using these parameters with the added integration of ES, which has the aim of reflecting the progress of work performed into the cost estimate. The resulting CEAC for each given time x is provided by Equation 2.

$$GGM(x) = \alpha e^{[-e^{(\beta-\gamma x}]} \qquad \text{Eq. 1}$$

$$\text{CEAC(x)=AV(x)+(GGM(CF(x)-GGM(x))*BAC} \qquad \text{Eq. 2}$$

where AV(x) is the actual cost of work performed incurred at time x, BAC the budget at completion, here referred to as the originally estimated cost baseline, and CF(x) is the completion factor, which is defined as the inverse of SPI(*t*) computed using the ES method. Therefore, the CF(x) equals one when the project is on time, less than one when it is ahead of schedule and greater than one if it is experiencing a delay. The decision to use this forecasting model as the basis for the development of a new algorithm comes from its good level of accuracy and computational simplicity (Narbaev and De Marco, 2014; Hazir, 2015).

This new methodology integrates the risk CC component into the base model. A contingency budget, which includes all management contingency reserves for unplanned changes to project scope and cost (PMI, 2013), is usually assessed using various available quantitative methodologies (Touran, 2003; Mak and Picken, 2000) and added at the beginning of the project to the cost baseline estimate in order to come up with a risk-adjusted budget at completion, here named to as BAC_{adj}. As long as the activities required to execute a project unfold, the cost baseline is cumulatively spent according to an S-shaped curve line that is well fitted by the GGM identified by the base model. Similarly, the contingency budget is a reserve account that is likely to be consumed along the project execution as per a reversed S-curve line, which can be modelled via a GGM (Figure 1). As far as the project progresses, the total initial contingency budget is going to be gradually used by the project team for activating risk corrective actions until most of the CC account is spent (Gutierrez and Kouvelis, 1991). Indeed, it can be reasonably assumed that the available remaining CC is gradually spent with the same, although reverse, behaviour of PV progress. Under the simplified assumption that the initial contingency budget is a predetermined k percentage portion of the BAC, the curves of cumulative BAC and cumulative contingency budget can be modelled as in Figure 1.

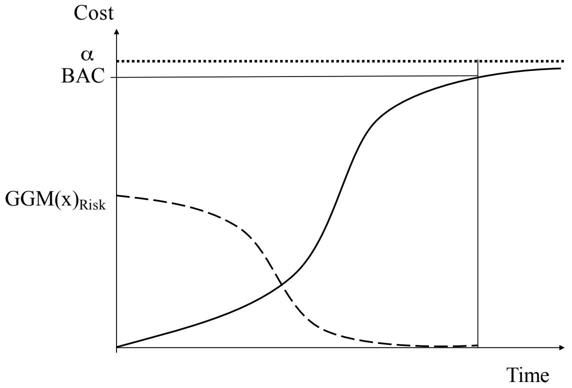

Figure 1. Behaviour of cumulative BAC and risk CC

Under these assumptions, the risk CC at any time *x* can be written as per Equation 3.

$$GGM(X)_{Risk} = \alpha - GGM(x)*k \qquad \text{Eq. 3}$$

In this way, GGM(*x*) estimated by non-linear regression is used to describe both the accumulation of actual cost incurred and the consumption of the contingency budget: at any point in time x, with corresponding CF(*x*), the project sums actual cost and residual contingency. Moreover, the introduction of the CF(*x*) allows to capture the trend of risk contingency by using it as a point on Equation 3. Therefore, the BAC is corrected with the residual CC, which changes at every time x with the behavior represented in Figure 1. The resulting BAC adjusted (BAC_{adj}) is modeled by Equation 4.

$$BAC_{adj} = BAC * \{1+k[\alpha-GGM[CF(x)]]\} \qquad \text{Eq. 4}$$

k is the CC expressed as a percentage of BAC. By replacing the initial BAC with BAC_{adj} into Equation 2, one can obtain Equation 5.

$$CEAC(x) = AC(x) + \{GGM[CF(x)] - GGM(x)\} * BAC * \\ *\{1+k[\alpha-GGM[CF(x)]]\} \qquad \text{Eq. 5}$$

4. Methodology

The given risk-integrated model for CEAC is evaluated on eight cases of various infrastructure, building construction and renovation projects with EVM data. The projects are listed in Table 1, where the columns report the number, Planned Duration (PD), Actual Time (AT), status at final completion, BAC and actual cost at completion (CAC) expressed in thousand amounts of local currency, respectively. The projects have varied nature and range of PD and BAC to better understand the applicability of the methodology. They also present various combinations of final cost and time performance compared to their original targets: four projects end with cost overruns and delayed finish (CO-LF), two with cost underrun and early finish (CU-EF), one overruns cost but finishes earlier than expected (CO-EF), and only one is completed on budget and on schedule (OB-OS).

	PD	**AT**	**Status**	**BAC**	**CAC**
1	15	16	CO-LF	57,747	61,564
2	10	12	CO-LF	58,000	59,183
3	9	13	CU-LF	360	349
4	9	12	CO-LF	2,875	3,247
5	10	9	CO-EF	906	952
6	10	10	OB-OS	12,563	12,563
7	13	14	CU-LF	12,592	12,585
8	20	27	CO-LF	17,691	20,238

Table 1. Case projects

Early (10-25%), middle (45-65%) and late stage (70-95%) cost estimates are calculated with the proposed risk-adjusted model for each project according to the following procedure. First, the GGM's *α*, *β* and *γ* parameters are obtained by non-linear regression. For this, x time data normalized with respect to PD are used as the predictor for the GGM model. Corresponding AV and PV cost data y (AV data normalized from time zero to AT and PV data normalized from AT onto project completion with respect to BAC) are used as the response variable (Narbaev and De Marco, 2014). The complete procedure for obtaining the values for the three above parameters are given in Narbaev and De Marco (2014). Second, Equation 5 is applied to produce the estimates.

Then, to test accuracy and stability of the estimates at the various stages of project development, the percentage error (PE%) is calculated with Equation 6 as the relative deviation of the CEAC from actual CAC.

$$PE\% = \frac{CEAC - CAC}{CAC} * 100\% \qquad \text{Eq. 6}$$

PE% results are compared to the estimate accuracy computed for the base model to verify whether improvements are obtained with the new proposed model.

Finally, a sensitivity analysis of the percentage portion of BAC *k* within a range defined in literature (Smith and Bohn, 1999) is carried out to confirm the validity of the model regardless of the value of the predetermined risk contingency budget. The analysis is complemented by a study on accuracy of the average and variance distribution for both the single project and for the set of projects.

5. Results

From the analysis of results reported in Table 4, it can be observed that for six out of eight early estimates the risk-adjusted model generates better estimates than the base model (projects #1, 2, 4, 5, 6 and 8). For mid stage estimates, however, only five projects out of eight (projects #1, 2, 4, 5 and 8) have more accurate estimates when using the risk-adjusted model and, in late stages, this count goes down to four projects (#1, 4, 5, and 8).

Time	Algorithm		Prj1	Prj2	Prj3	Prj4	Prj5	Prj6	Prj7	Prj8
		CAC	*61,564*	*59,183*	*349*	*3,247*	*952*	*12,563*	*12,585*	*20,238*
Early	Base	CEAC	59,935	56,611	367	2,930	919	12,505	12,656	17,293
Early	Base	PE [%]	-2.65	-4.35	5.24	-9.75	-3.38	-0.46	0.56	-14.55
Early	Risk	CEAC	60,880	57,724	370	2,953	920	12,532	12,657	17,293
Early	Risk	PE [%]	-1.11	-2.47	5.96	-9.05	-3.35	-0.24	0.58	-14.55
Mid	Base	CEAC	55,125	57,192	397	3,214	905	12,756	12,947	18,822
Mid	Base	PE [%]	-10.46	-3.37	13.68	-0.99	-4.93	1.54	2.88	-7.00
Mid	Risk	CEAC	55,360	57,780	400	3,246	905	12,794	12,975	18,822
Mid	Risk	PE [%]	-10.08	-2.37	14.52	0.00	-4.89	1.84	3.10	-6.99
Late	Base	CEAC	59,102	59,832	356	3,216	935	12,955	13,411	19,480
Late	Base	PE [%]	-4.00	1.10	2.06	-0.95	-1.71	3.12	6.57	-3.75
Late	Risk	CEAC	59,168	60,068	357	3,231	935	13,059	13,462	19,480
Late	Risk	PE [%]	-3.89	1.49	2.36	-0.48	-1.69	3.95	6.97	-3.75

Table 4. CEACs and PE with both models at various stages of project completion

The estimation method proves to generate accurate cost forecasts, especially in the early stages of a project, while the accuracy decreases gradually as far as the project progresses. In fact, when the progress is around 20%, as much as 75% of the project estimates get closer to the actual CAC.

This is an interesting result because it is during the early stage of a project that reliable estimates are needed for project managers to take timely and effective corrective actions. At this stage, just a few EVM data are available and this usually generates difficulties in obtaining accurate and reliable CEACs; the initial stage is one that has potential to influence the final project results by applying inexpensive performance corrections and adjustments.

It is now opportune to understand if the *k* parameter affects the validity of the model. In fact, the size of the CC budget, expressed as a function of the BAC, could influence the result of the CEAC. To this end, a sensitivity analysis is conducted in all early, middle, and late stages by varying *k* from 2.5 to 12.5%, which is reported by the literature to be a range of the risk contingency in relation to BAC (Smith and Bohn, 1999; Mak and Picken, 2000). The results in Table 5 show that there is a substantial stability of the algorithm to *k*% values and this proves the model’s applicability regardless of the contingency value. The PE’s standard deviation (SD) appears as not negligible, however it is lower that in the base formulation: this reaffirms the validity of the proposed methodology

Moreover, Table 6 shows how the average forecasts obtained with the proposed methodology slightly underestimate the final cost (CAC). However, the CEAC becomes more accurate as k increases. This can be interpreted as a further justification and viability of the proposed risk-adjusted model that proves more accurate when a larger risk contingency budget is estimated on top of baseline cost and when risk plays an impacting role on the future behaviour of project performance.

#	PE	2.5%	5.0%	7.5%	10.0%	12.5%
1	Average	-5.53	-5.36	-5.20	-5.03	-4.86
	SD	4.27	4.37	4.48	4.59	4.71
2	Average	-1.93	-1.66	-1.39	-1.11	-0.84
	SD	2.74	2.57	2.41	2.26	2.11
3	Average	7.15	7.30	7.46	7.61	7.77
	SD	6.06	6.12	6.18	6.24	6.30
4	Average	-3.71	-3.53	-3.36	-3.18	-3.00
	SD	5.07	5.08	5.08	5.09	5.10
5	Average	-3.33	-3.33	-3.32	-3.31	-3.30
	SD	1.61	1.60	1.60	1.60	1.59
6	Average	1.51	1.62	1.74	1.85	1.96
	SD	1.87	1.94	2.02	2.09	2.17
7	Average	3.39	3.44	3.50	3.55	3.60
	SD	3.08	3.13	3.17	3.22	3.27
8	Average	-8.43	-8.43	-8.43	-8.43	-8.43
	SD	5.54	5.54	5.54	5.54	5.54

Table 5. Sensitivity analysis

PE	***k*=2.5**	***k*=5.0**	***k*=7.5**	***k*=10.0**	***k*=12.5**
Average	-1.36	-1.24	-1.12	-1.01	-0.89
SD	5.94	5.96	5.99	6.01	6.04

Table 6. Variability of PE for the set of projects (in %)

6. Conclusion

We present here a combined index-regression based model to compute CEAC and apply it to a sample of case study projects. This model integrates into a unique forecasting equation the impact of both integrated cost-schedule performance and nonlinear consumption of the CC during the development of a project. The method performs well under a variety of conditions and performance situations: it provides for accurate and stable CEACs during the various stages of a project development and with different size of the original CC budget.

Both theoretical and practical implications can be drawn from this model. The cost–schedule-risk relationship captured by our model is a contribution to create a tight connection between EVM and risk management research and to capture the dynamics of managing the CC escrow accounts in running projects. As a practical implication, the model is proposed in integration to ES-based nonlinear CEAC formulae as a contingency-adjusted CEAC tool to be used especially during the early and mid stages of project development.

Future research is in replacing the assumption that CC is consumed in line with the project's progress with different CC management profiles that could better encapsulate the expenditure of the contingency based on risk incurred along the project execution (Xie et al., 2012). Also, the method is suggested for extended application to a variety of projects in different sectors.

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