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Earned Value and Cost Contingency Management: A FRAMEWORK MODEL FOR RISK ADJUSTED COST FORECASTING

ABSTRACT

This paper proposes a novel framework model that considers different behaviors of cost contingency (CC) consumption in forecasting risk adjusted final cost during the project execution. The model integrates the dynamics of how project managers can spend their contingencies into three S-shaped cost growth profiles to compute risk adjusted cost estimates at completion (CEAC). The three cost curves are modeled by the Gompertz growth model using nonlinear regression. Respectively, the framework embeds three different CC consumption rates to represent three main categories of aggressive, neutral or passive managerial attitudes in responding to project risk. The usage and viability of the model is demonstrated via a earned value management (EVM) dataset. The paper contributes to the body of knowledge by bridging the gap between the theories of EVM and CC management and provides project managers with a model to estimate the range of possible cost estimates at completion depending on the managerial policies that can be activated driven by different risk attitudes.

1. Estimating Risk Adjusted Cost at Completion

Earned value management (EVM) has been considered by scholars and practitioners as an objective methodology to monitor the project status and provide time and cost forecasts. It integrates schedule, cost, and scope measurements into a single project monitoring system. In particular, based on current project progress the EVM system assists in computing the cost estimate at completion (CEAC) as an estimate of the expected final cost of an ongoing project (Anbari, 2003).

A conventional EVM system uses the cost performance index (CPI) and the schedule performance index (SPI) and their combinations to compute CEACs (PMI, 2011). This is known as a traditional index based approach where project managers rely on performance indicators to identify potential deviations from schedule and cost baselines and to implement corrective actions for bringing their projects back on track (Christensen at al., 1992). Kwak and Anbari (2009) noted that the EVM impact on project management was low in 1970s and 1980s but has been growing since then and the EVM and related methods for measuring project performance will grow rapidly, particularly due to governmental regulations (e.g., of Australia, UK, USA) requiring systematic cost and schedule evaluation in managing government projects.

With regard to the EVM cost forecasting, recent studies have: adapted the Bayesian statistical inference for more reliable estimates (Caron et al., 2013), suggested a linear transformation method to improve the predictive power of the planned value for CEAC (Chen, 2014) and proposed a framework that that incorporates a project's key performance indicators into the risk performance index to predict risk adjusted CEACs (Babar et al., 2016). In their study, Narbaev and De Marco (2014) proposed a new regression model to improve CEACs for ongoing projects, Batselier and Vanhoucke (2015) evaluated the accuracy of different CEAC forecasting methods and De Koning and Vanhoucke (2016) addressed stability of CPI and SPI by identifying project characteristics which may influence the indexes.

Despite the availability of recently proposed CEAC approaches that have been developed to overcome limitations of the traditional EVM cost forecasting methods, little research has been conducted to consider cost contingency (CC) as an intrinsic factor of project performance and to integrate it into the CEAC methodologies. Also, current CEAC methods do not map the dynamics of CC consumption during project execution (Barraza and Bueno, 2007). In fact, the process of computing CEAC and managing CC are typically used separately to study the project's cost performance and are rarely integrated (Xie et al. 2012).

Provided this, there is no method that integrates both CC and CEAC calculations into one single forecasting methodology. However, the project management practice calls for methodologies able to integrate the process of CC management into CEAC in order to capture the impact of uncertainty and risk in final cost forecasts (Narbaev and De Marco, 2014). In fact, to cover for risk and unforeseen changes that may occur during project execution and to show the project's risk tolerance, project managers typically establish an initial CC as an extra budget in addition to a project baseline estimate (Xie et al., 2012; PMI, 2011). Project managers predict the final cost of a project not only based on past performance, but also based on the expected consumption of such CC, which is in turn affected by the managerial behavior and risk attitude (De Marco et al., 2016b). However, available CEAC methodologies do not take into account for the possible consumption of CC during the course of a project and managerial attitude towards risk.

Based on existing gaps, there is a need for proposing a risk adjusted CEAC methodology that introduces CC as an inherent component of the cost growth curve of a project and considers the influence of managerial behavior towards CC consumption. To this end, a framework model is presented to compute CEAC of an ongoing project that considers different behaviors of CC consumption as a factor of final cost forecasts. The model is proposed as a contribution to the research community as it elaborates an integrated approach to EVM and CC management and for practical application to large and complex projects developed by governments and main contractors.

2. Research Background

2.1. S-Curves in Projects

In project management, S-curves are used to represent cumulative cost and resource utilization in projects depicted against the time axis. Such S-shaped patterns can be modeled by growth models to plot the behavior of cost accumulation in projects. Different methods exist to fit EVM data to model the project's progress or final cost among which regression modeling is prominent (Christensen at al., 1992). Such fitting is achieved as the mathematical forms and parameters of the growth models reflect project development and satisfy requirements for a typical S-shaped cost pattern. At an early stage of project development, the work typically progresses at a slow pace due to, e.g., field preparation and/or resources deployment. Then, as activities unfold at a middle stage of the project, the work speeds up increasing the cost growth rate to a maximum, and, finally, decreasing its rate to zero at the project completion. The S-curve pattern of project cost is driven by the multiple interconnected activities most of which occur in the middle of a project's life and close in to a small number again (as at the project start) as work is eventually completed (Cioffi, 2005).

However, each individual project is unique in its nature and an S-curve pattern of one project is rarely observed in others. Therefore, each project produces an S-curve with different geometric properties, such as the location of peak cost expenditure along the time axis and the shape of the curve. Also, S-curves representing planned or actual cumulated progress are not smooth and often are highly uneven (Chao and Chien, 2010).

With the above consideration, a universe of projects with S-curves of different peak cost expenditure locations and shapes are grouped into three families: front-loaded, mid-loaded, and back-loaded. The grouping of projects, based on distribution of their budget with respect to their duration, allows a closer approximation of the parameters of the peak location and shape of an S-curve. Cioffi (2005) applied an analytic parameterization to fit an S-curve to project cost data and used numerical approximation of shape and slope parameters of an S-curve for representing the three loads of cost distribution in projects. The benefit of such approximation and grouping is that they provide for flexibility in generating smooth S-curve profiles. In the family of front-loaded projects most of the work is performed in the first half of the project life. The cost density curve of such projects showing the cost expenditure at each given period is right-skewed with a long tail by the end of the project. Such projects are familiar with their work accelerating fast and the cost growth rate steeps at the beginning. The cost S-curves of mid-loaded projects are represented as symmetric about the middle stage of the project progress. In contrast, back-loaded projects experience most of work in the second half of their life and therefore depict their density curves left-skewed. In such projects work speeds up slowly and increases as activities unfold and reaches its maximum rate after the project midlife.

2.2. Cost Contingency Management during Project Execution

Calculations pertinent to cost expenditures can be decomposed into two main types: project budget estimations that are made before the project starts and CEAC forecasting during the project execution. Various sources of risk influence both types of cost calculations and the way project managers estimate, allocate and manage appropriate contingency budgets for an effective project monitoring (Uzzafer, 2013).

When a project kicks off, the cost contingency is used to address uncertainty and risks and to keep the project within agreed schedule, cost, and scope requirements. The contingency budget can be defined as a percentage of a project's budget, as a fixed monetary value, or developed using various quantitative methodologies (Xie et al., 2012) and added at the beginning of the project to the project cost estimate in order to come up with a cost baseline. However, CC should be not only properly calculated and assigned in the budget estimation process, but also wisely monitored, controlled, and consumed during the project execution (Barraza and Bueno, 2007).

Several studies suitably consider a process of CC management as an integral and important part of project monitoring. In fact, such contingency reserves are aimed at covering probable cost overruns above the project target estimates (PMI, 2013). In this regard, Touran 2003 presented a probabilistic model that accounts for uncertainties in project cost and calculates CC based on the level of statistical confidence specified by a project owner. His model was based on the estimate for the change rate, average cost of change, and the variation coefficient of cost of change. Cioffi and Khamooshi (2009), considering project risks with corresponding impacts and probabilities, developed a method to estimate the total potential impact at a given certainty to allow project managers set aside corresponding contingency funds. Xie et al. (2012) presented a method for project cost contingency forecasting and updating based on value at risk during the project execution. Actually, the managerial process of defining, monitoring and controlling the cost contingency during the project execution may influence the project final cost (Ford, 2002) and, hence, the CEAC calculation.

2.3. An Outline of the Original CEAC Model

There is no method that integrates both CC and CEAC calculations into one single forecasting methodology and that available CEAC methods do not take into account for consumption of CC during the project execution and managerial attitudes towards risk. Narbaev and De Marco (2014) noted that it was opportune to integrate into CEAC methodologies uncertainty and risk analysis able to capture risk events into CEAC formulation.

Provided this, the risk adjusted CEAC framework model proposed in this paper (hereafter named as $CEAC_{risk}$) is built upon an original CEAC methodology (hereafter CEA_{Corig}) developed by Narbaev and De Marco (2013, 2014). In their study, Narbaev and De Marco (2013) proposed this EVM cost forecasting methodology which was based on the Gompertz growth model and used nonlinear regression modeling. The model integrated the earned schedule (ES) concepts into its equation to account for schedule influence in cost forecasts. Recently, extended applicability and reliability of this model was provided by comparing its estimates' accuracy, precision, and timeliness with ones computed by traditional index based approaches (Narbaev and De Marco, 2014). This CEA_{Corig} model forecasts the project final cost at particular time x as presented in Equation 1.

$$CEAC_{orig}(x) = AC(x) + [GGM(CF(x)) - GGM(x)] \ast BAC \quad (1)$$

where AC – Actual cost of work performed; GGM – a Gompertz growth model (GGM) function; CF – Completion factor, which indicates the forecasted completion time yielded to unity and is an inverse of SPI(t) – the time based SPI as introduced by Lipke (2003), and BAC – Budget at completion, an original cost baseline of a project.

GGM(CF(x)) represents a total BAC adjusted to estimated time at completion while GGM(x), based on the project progress by actual time, represents to date BAC spending; both values are normalized to unity. Given this, the second summand in Equation 1 forecasts the remaining budget to project completion, a portion of BAC, which has nonlinear S-curve pattern described by the GGM. BAC decreases over time as the project approaches its completion. The GGM function is defined as per Equation 2.

$$GGM(x) = \alpha e^{[-e^{(\beta-\gamma x)}]} \quad (2)$$

where α – the value representing the asymptotic project final cost as time (x) approaches infinity; β – the parameter showing the project initial size, *i.e.*, the y-intercept, and governs a curve's location along the x-axis; and γ – the scale parameter that manages the cost growth rate accounting for a curve's shape. All the three parameter values are found by nonlinear regression analysis. The model has the inflection point at time $x=\beta/\gamma$ when its growth is $GGM(x)=\alpha/e$ and the cost growth rate reaches its maximum ($MaxRate=\alpha\gamma/e$). The $x=\beta/\gamma$ models the location of the GGM curve, *i.e.*, its movement along the x-axis, to the left or right, while the γ parameter scales its shape. Both the location and shape of the model curve are the function of the above three parameters.

The uniqueness of this growth model when applied to calculate CEAC is that its nonlinear pattern is able to represent S-curve behavior of project cost. In other words, a BAC residual decreases over time and behaves as S-shape like: slow pace at the project beginning, the speeding up work by the middle, and declining growth rate at completion. The full stepped modeling process of $CEAC_{orig}$ with explanations and in depth derivations is presented in Narbaev and De Marco (2014).

3. Methodology

3.1 Modifying the Original CEAC Model

The portion of the original CEAC model, GGM(CF(x))-GGM(x), which nonlinearly accounts for the remaining portion of BAC, is presented with a new notation Ω, as given in Equation 3. The portion of the original model is empirically constructed by Narbaev and De Marco (2014).

$$\Omega(x)= GGM(CF(x)) - GGM(x) \quad (3)$$

The original CEAC model is then modified for inclusion of the CC component into cost forecast calculations. The mathematical transformation from $CEAC_{orig}$, as defined in Equation 1, to $CEAC_{risk}$ is given in Equation 4.

$$CEAC_{risk}(x) = AC(x) + [GGM(CF(x)) - GGM(x)] \ast BAC \ast (1+k) = AC(x) + [GGM(CF(x)) - GGM(x)] \ast BAC + [GGM(CF(x)) - GGM(x)] \ast BAC \ast k = AC(x) + \Omega(x) \ast BAC + \Omega(x) \ast BAC \ast k = AC(x) + \Omega(x) \ast BAC + \Omega(x) \ast CC \quad (4)$$

AC is the sum of actual cost of work performed and actual expenditure of CC. The sum of BAC and the total CC is defined as the performance measurement baseline, which is an approved, integrated scope-schedule-cost plan for the project work against which project execution is compared to measure and manage performance (PMI, 2011). Therefore, during project execution, this theoretically derived $CEAC_{risk}$ model is able to represent dynamics of CC consumption in the final cost estimates. CC is traditionally defined as a percentage of the project budget, which is set during the project planning phase (Xie et al. 2012). Given this, CC is defined as per Equation 5.

$$CC = BAC \ast k \quad (5)$$

where k is the percentage of BAC.

Under the simplified assumption that the initial CC is a predetermined k percentage portion of BAC, the curves of both cumulative BAC and CC are modelled by a new notation, Ω(x), which in turn is built on the GGM as per Equation 2. Then CEACorig is modified to represent the estimates of both project's cost and contingency budget, separately. This implies that, as far as the project progresses, the total initial contingency budget is gradually consumed by the project team for activating risk corrective actions until the CC escrow account is spent (Ford, 2002).

3.2 The Proposed CEAC Framework Model

The $CEAC_{risk}$ framework includes three different forms that are defined to model the way the CC consumption progresses over time in a project. As long as the project activities unfold, BAC is cumulatively spent according to an S-shaped curve that is well fitted by the GGM. Similarly, the contingency budget is a reserve account that is consumed along the project execution as per a reversed S-shaped curve, which is dependent on BAC as a function of the GGM (Equation 2). In addition of being influenced by the GGM, the contingency consumption behavior is modelled by the CC factor, Ω, and can take either of the three consumption forms (shapes). The assumption is that the contingency spending is spent proportionally to BAC with a constant CC rate (CCR) or not proportionally with a changing CCR.

This assumption establishes the way how CC is spent by project managers. With this regard, Ford (2002) reported results of different CC management practices and developed a model to test the CC spending behavior of project managers. He distinguished between aggressive and passive CC management strategies to respond to risk. According to him, a project manager with an aggressive strategy reallocates CC quickly, uses it to control schedules, resolves unexpected problems, and applies funds early into a project life. Under a passive strategy, CC is reallocated slower and postponed until it is used to meet critical objectives by a project end. De Marco et al. (2016a) proposed the same concept of aggressive and passive CC management strategies to a complex construction project using the system dynamics modeling. The model allowed for simulation of influences of main stakeholders over the CC management process and explored behaviors of project managers. It was revealed that with a passive or reactive risk management policy, risk is ignored at the beginning and then reactively managed later in a project.

Provided this, CC is spent aggressively as early as possible with a comparatively higher CCR early in a project. In contrast to an aggressive strategy, a project manager with a passive strategy utilizes CC as late as possible with a comparatively higher consumption rate by a project end.

Also, such behaviors in managing risk in part can be explained by a project manager's tolerance for risk. Three commonly used types of risk tolerance are a risk seeker, a risk neutral, and a risk averter. In this regard, Kerzner (2013) noted that with a risk neutral manager utility (satisfaction from a payoff) rises at a constant rate. A risk taker's utility rises at an increasing rate when more money is at stake while a risk averter's utility rises at a decreasing rate. In other words, a risk neutral manager spends CC at a constant rate. With a risk taker, more CC is available at project beginning which is consumed with a higher CCR compared to the contingency spending at a project end. With a risk averter, more contingency is available at project beginning which is spent with a lower CCR compared to the spending at a project end.

The behavior of the contingency consumption curve depends on the type of CCR, which is in turn governed by the form of the Ω factor. With this proposition, the framework model distinguishes these three forms of CCR as: a constant CCR governed by Ω, decreasing CCR governed by Ω^2, and increasing CCR governed by $\sqrt{\Omega}$ with their respective equations introduced in Equation 6, 7, and 8, respectively.

$$CEAC_{risk}(x) = AC(x) + \Omega(x) \ast BAC + \Omega(x) \ast CC \quad (6)$$

$$CEAC_{risk}(x) = AC(x) + \Omega(x) \ast BAC + \Omega(x)^2 \ast CC \quad (7)$$

$$CEAC_{risk}(x) = AC(x) + \Omega(x) \ast BAC + \sqrt{\Omega(x)} \ast CC \quad (8)$$

To account for risks in projects, $CEAC_{orig}$ was considerably refined. This was achieved by introducing two major modifications into the original model. First, the proposed model is now able to represent dynamics of CC consumption in the CEAC computation. This is represented by the third summand in Equation 4. Second, the model is now referred to as a

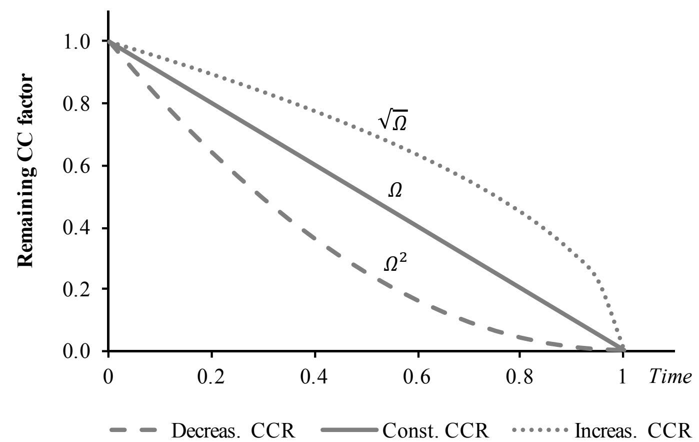


FIGURA 01. *The contingency spending rates corresponding to the model's three forms.*

framework that can take three different forms which respectively represent three managerial attitudes in responding to risk. These are the three CC consumption rates a project manager may spend a contingency account which are presented by Equation 6, 7, and 8, respectively.

Figure 1 depicts the respective consumption curves of the model's three CC forms.

The Model Form *#1* (Equation 6): Constant CCR. The rate of the contingency budget consumption is constant and equal to 1 (the result of the 1st derivative of $f'(\Omega)$) and linear to BAC progress governed by Ω(x), which in turn has a nonlinear pattern due to the S-like shape of the GGM. Such a form presents a CC spending proportional to the progress of the budget expenditure and its rate does not change and is equal to 0 (the result of the 2nd derivative of $f''(\Omega)$) as the project progresses. This implies that project managers tend to spend their contingency budgets along with the same S-curve behavior as the project budgeted cost. For example, in case of a front-loaded project, they spend most of CC at the first half the project life.

The Model Form #2 (Equation 7): Decreasing CCR. CCR decreases nonlinearly with respect to BAC progress that is presented by the 1st derivative of the Ω^2 variable (2Ω). This change in the decreasing rate of CC consumption over time is constant and is ruled by the 2nd derivative of $f''(\Omega^2)= 2$. In this form, when the variable Ω is normalized to unity, the decrease in CCR is by 0.02 for each tenth change of the value of Ω. This constant change in the rate is governed by Ω^2, which in turn has a nonlinear pattern due to the S-shape of the GGM curve line. Such a form implies that project managers tend to spend the most of the contingency budget with its highest rate during the project early stages (demonstrated in Figure 1) and the rate of CC consumption decreases as the project progresses. This spending pattern is influenced in addition to the way the S-like curve of the project budget impacts the CC consumption.

The Model Form #3 (Equation 8): Increasing CCR. The rate of CC spending increases nonlinearly with the BAC and its change over time is ruled by $\sqrt{\Omega}$, which has a nonlinear pattern due to the S-like shape of the GGM. Its 1st derivative ($1/(2\sqrt{\Omega})$) represents the rate of contingency expenditure at each time period, while the 2nd derivative ($-1/(4\sqrt{\Omega^3})$) shows how the change in the rate, *i.e.*, the acceleration of CC consumption, increases as a project develops. Both CCR and its acceleration increase non proportionally to $\sqrt{\Omega}$ itself and are nonlinear. This suggests that a back-loaded expenditure of the contingency budget is preferred: a reduced CC consumption rate at the beginning of the project is then followed by an accelerated usage of the contingency by the end of the project.

4. Demonstration of the Framework Model

In order to demonstrate its usefulness and viability, the CEACrisk framework model is applied to a hypothetical set of EVM data. The dataset characterizes the three families of S curve profiles of the universe of projects: front-loaded, mid-loaded, and back-loaded. The application of the proposed methodology to a notional dataset with full EVM characteristics allows us to demonstrate the model's three forms with different contingency consumption behaviors on the same dataset. Table 1 presents the project's EVM and CC data for the three S curve categories. The project's BAC is worth $28,999,000 with the planned duration of 21 months. The CC budget is $2,900,000 defined as a fixed percentage (10%) of BAC during the project planning. The performance measurement baseline is therefore $31,899, 000 and the actual cost at project completion is $32,438,000.

The usage of the proposed $CEAC_{risk}$ framework model is demonstrated using the data of the front-loaded project. The paper shows $CEAC_{risk}$ computations for the model's forms with constant, decreasing, and increasing CC consumption rates using Equation 6, 7, and 8, respectively, when the project is in its early stage, e.g., when 24% of the project work is complete.

Time points, months	Front-loaded project				Mid-loaded project				Back-loaded project				CC consumption under different behavior		
	PV	EV	AC	EV%	PV	EV	AC	EV%	PV	EV	AC	EV%	Ω	Ω^2	$\sqrt{\Omega}$
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	526	500	551	2	450	400	501	1	330	300	350	1	120	300	50
2	1800	1751	1900	6	980	900	1001	3	701	650	750	2	240	600	100
3	3200	3001	3401	10	1589	1498	1548	5	1101	990	1100	3	360	900	150
4	4791	4801	4901	17	2298	2001	2200	7	1564	1393	1500	5	500	1100	200
5	6801	7000	6894	***24***	3201	2905	3198	10	2001	2001	2286	7	630	1300	250
6	9808	9600	10330	33	4399	4400	4567	***15***	2698	2501	3000	9	750	1500	300
7	13289	12901	12954	44	6001	6200	6478	21	3303	2901	3100	10	850	1700	350
8	15901	15568	15798	***54***	8001	7898	8395	27	3901	3700	3900	13	1000	1900	450
9	18100	18450	19320	64	10547	10346	10674	36	4700	4484	5100	***15***	1150	2100	550
10	20200	20000	21124	69	13300	13001	13497	45	5500	5390	5501	19	1300	2250	650
11	21879	21429	21901	74	16260	15833	15676	***55***	6801	6590	6401	23	1450	2400	750
12	23451	22901	23439	***79***	18800	18500	18501	64	8438	8405	8901	29	1600	2500	850
13	24901	24341	24501	84	20458	20701	21236	71	10201	10598	10599	37	1700	2600	950
14	26001	24784	25321	85	21980	21001	21501	72	12575	12494	12810	43	1800	2650	1050
15	26901	26301	26001	91	23101	22501	23296	***78***	15771	15000	15219	***52***	1900	2700	1150
16	27900	27894	27801	96	24001	23601	25601	81	18791	18499	18801	64	2000	2750	1250
17	28541	28101	28231	97	25399	24801	25810	86	21891	21501	22439	74	2150	2800	1400
18	28750	28389	28501	98	26239	26610	28201	92	24401	25479	26901	***88***	2300	2820	1550
19	28864	28599	28832	99	27399	27598	28546	95	26383	26749	27198	92	2400	2840	1700
20	28945	28659	28901	99	28398	28349	28901	98	27895	27600	28100	95	2500	2850	1900
21	28999	28750	29124	99	28999	28401	28955	98	28999	28193	29899	97	2600	2870	2100
22		28810	29436	99		28650	29386	99		28650	29400	99	2750	2880	2400
23		28999	29538	100		28999	29538	100		28999	29538	100	2900	2900	2900

Note: The EV% values in bold italics represent early, mid, and late forecast periods.

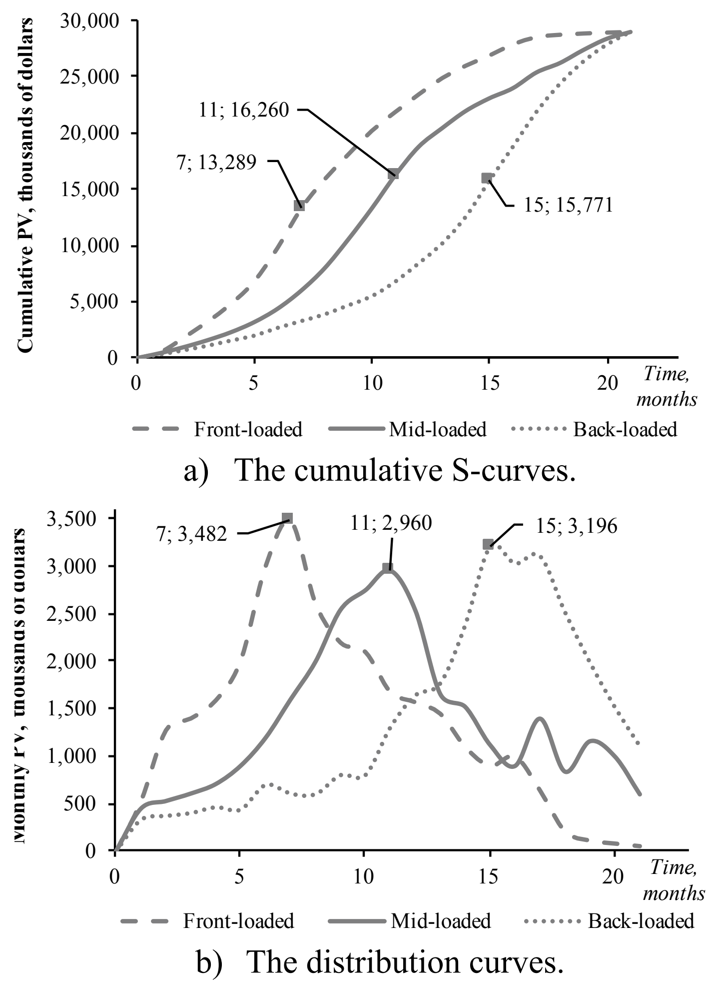
TABLE 01. *Cumulative EVM and CC data for the three families of projects, in thousands of dollars.*

To this end, first, the value of $\Omega(x)$ needs to be find which is equal to GGM (CF (x)) - GGM (x). For this, the three parameters of the GGM (Equation 2) are computed through nonlinear regression curve fitting (Narbaev and De Marco, 2014). Both time (a predictor variable) and cost (a response variable) units are normalized to unity for data entry into the equation. Each next time point is a cumulated portion of this unity with the final time point representing the planned duration of a project. Each time point (x) has a corresponding cost point which is formed as follows. The values of AC from time zero (x=0) to time now are normalized to unity (i.e., BAC=1.00) while the values of the planned value (PV) from time now onto project completion. Then, the normalized values of to date AC and PV are combined to form the values of the response variable (*y*) in the GGM to run the nonlinear regression. Now, both time and cost units have final values equaling 1.00. To run the regression, the initial values of the three parameters are set as 1.00 with the confidence level of 95%. This choice is made considering issues related to defining initial values of the GGM parameters and the Gauss–Newton approximation algorithm (Seber and Wild, 1989). Finally, the values of the three parameters are obtained. The statistical analysis can be performed using other nonlinear regression platforms.

The computed values of the model's parameters are α = 1.04, β = 1.59, and γ = 5.28. This results in GGM (CF(0.99)) - GGM(0.24) = Ω(0.24) = 0.75. This value represents the remaining portion of the project's BAC at forecast time when 24% of work is accomplished. AC, the sum of to date actual cost ($6,894,000) and CC spent with the constant CCR (represented by the remaining CC factor Ω, $630,000) is equal to $7,524,000. Plugging in the above values to Equation 6, CEACrisk is equal to $31,595,000. The forecast accuracy is measured by Percentage Error (PE, %), which is the difference between $CEAC_{risk}$ and the actual cost at project completion expressed as a percentage of the actual cost at project completion. Its negative value implies estimate's underestimation while a positive value suggests overestimation. The PE of $CEAC_{risk}$ for this example is -2.60%. In this forecast, CC consumption behaves as per Model Form #1 where the contingency spending rate is constant and proportional to the project budget as shown in Figure 1.

Forecast stage	Model form and factor	Front-loaded project forecast (EV% complete is 24 - Early, 54 – Mid, and 79% for Late stages)							Mid-loaded project forecast (EV% complete is 15 - Early, 55 – Mid, and 78% for Late stages)							Back-loaded project forecast (EV% complete is 15 - Early, 52 – Mid, and 88% for Late stages)						
		AC	CC spent	Ω	CC factor	Cont EAC	ContEAC, PE%	CEAC, PE%	AC	CC spent	Ω	CC factor	Cont EAC	ContEAC, PE%	CEAC, PE%	AC	CC spent	Ω	CC factor	Cont EAC	Cont EAC, PE%	CEAC, PE%
Early stage	Form 1, Ω	7524	630	0.75	0.75	2818	-2.82	-2.60	5317	750	0.84	0.84	3184	9.78	-1.08	6250	1150	0.95	0.95	3891	34.19	12.23
	Form 2, Ω^2	8194	1300	0.75	0.57	2951	1.77	-2.19	6067	1500	0.84	0.70	3542	22.15	0.03	7200	2100	0.95	0.89	4691	67.78	14.70
	Form 3, $\sqrt{\Omega}$	7144	250	0.75	0.87	2769	-4.51	-2.75	4867	300	0.84	0.92	2957	1.95	-1.78	5650	550	0.95	0.97	3369	16.19	10.62
Mid stage	Form 1, Ω	16798	1000	0.48	0.48	2389	-17.78	-1.27	17126	1450	0.45	0.45	2762	-4.75	-2.71	17119	1900	0.54	0.54	3464	19.45	5.81
	Form 2, Ω^2	17698	1900	0.48	0.23	2561	-11.69	-0.73	18076	2400	0.45	0.20	2994	3.24	-1.99	17919	2700	0.54	0.29	3543	22.19	6.06
	Form 3, $\sqrt{\Omega}$	16248	450	0.48	0.69	2454	-15.39	-1.06	16426	750	0.45	0.67	2701	-6.87	-2.90	16369	1150	0.54	0.73	3280	13.09	5.24
Late stage	Form 1, Ω	25039	1600	0.19	0.19	2144	-26.07	-4.37	25196	1900	0.21	0.21	2497	-13.89	-2.07	24589	2300	0.36	0.36	3332	14.91	10.81
	Form 2, Ω^2	25939	2500	0.19	0.04	2602	-10.27	-2.95	25996	2700	0.21	0.04	2823	-2.65	-1.07	25239	2820	0.36	0.13	3187	9.92	10.77
	Form 3, $\sqrt{\Omega}$	24289	850	0.19	0.43	2106	-27.38	-4.48	24446	1150	0.21	0.45	2466	-14.96	-2.17	23839	1550	0.36	0.60	3280	13.12	10.65

TABLE 02. *The model results for the three families of projects, in thousands of*



a) The cumulative S-curves.

b) The distribution curves.

FIGURE 02. *The three families of projects of the sample dataset*

Forecast results via GGM	Front-loaded project; forecast stages			Mid-loaded project; forecast stages			Back-loaded project; forecast stages		
	Early	Mid	Late	Early	Mid	Late	Early	Mid	Late
α	1.04	1.04	1.03	1.08	1.09	1.09	2.42	2.42	2.35
β	1.59	1.58	1.62	1.89	1.85	1.85	1.87	1.86	2.87
γ	5.28	5.25	5.46	4.33	4.23	4.23	2.05	2.05	2.10
$x=\beta/\gamma$	0.30	0.30	0.30	0.44	0.44	0.44	0.91	0.91	0.89
$GGM(x)=\alpha/e$	0.38	0.38	0.38	0.40	0.40	0.40	0.89	0.89	0.86
$MaxRate=\alpha\gamma/e$	2.02	2.00	2.07	1.72	1.69	1.70	1.83	1.82	1.81

TABLE 03. *The Gompertz growth model's parameter values and characteristics for forecast calculations.*

The computations of $CEAC_{risk}$ for the other two forms of the framework model are also shown. The second form of the model represents CCR which is decreasing over time: an assumption that the most of the contingency budget is spent at the beginning of the project life and gradually decreasing. The third form assumes that project managers consume the contingency budget with less intensity at the beginning and its rate of spending increases over time with its highest rate by the end. Using their respective formulae, Equation 7 and 8, the cost forecasts of the second and third forms are 31,728,000 (PE=-2.19%) and $31,546,000 (PE=-2.75%), respectively. Table 2 presents the forecast results of early, mid, and late stages for all the three families of projects that are discussed in the next section.

Previously, the study noted about the three families of the universe of projects whose S-like curves differ in their location of peak cost expenditure along the time axis and shapes. Figure 2a demonstrates the three S-curves that result from our sample dataset. It can be seen that the shapes of the curves are different. These three curves represent the families of front-loaded, mid-loaded, and back-loaded projects, respectively. Figure 2b shows their monthly budget spending, i.e., density (distribution) curves. The points of inflection of the curves represent the period when the budget spending is the highest, i.e., the peak cost expenditure. The locations of the peak points are different along the x-axis. For instance, for the front-loaded project the peak is at month 7 with a cumulative budget of $13,289,000 and a monthly budget spending of $3,482,000. Also, the curves are not smooth and uneven in some periods. Such characteristics of S-curves are managed by the GGM that models the nonlinear relationship between schedule progress and cost.

Table 3 provides the results of the nonlinear fit characteristics of the GGM (Equation 2). For the early stage estimation of the front-loaded case, the value of the parameter α is 1.04, which suggests a final cost, normalized to unity, as the project tends to infinity. Its value varies from the lowest for the front-loaded to the highest for the back-loaded projects. Given this, it may be reasonably assumed that, on average, back-loaded projects bear greater risk subject to cost overruns. The parameter β governs the location of the curve along the time axis with its lowest value od 1.59 for the front-loaded projects. The parameter γ=5.28 scales the shape of the curve; the higher the value is the steeper the rise of cost accrual which suggests the higher growth rate. Given the parameters' values, the inflection point for the cost accrual is when about 30% of the time is complete and about 38% of the budget is spent. At this peak point the rate of budget spending is the highest among time periods which is represented by the relationship, $\alpha\gamma/e$=2.02.

5. Findings and Discussion

5.1 Risk Adjusted Forecast Results

Table 2 reports the results of the three forms of the proposed framework model when applied to compute CEACrisk of front-loaded, mid-loaded, and back-loaded projects at the three forecast stages.

The findings for the front-loaded family of projects are as follows. The Model Form #2 with decreasing CCR (represented by Equation 7 and managed by Ω^2) results as the most accurate in estimating the final cost at completion. This form suggests that a greater portion of the contingency budget is spent during the first part of the project life compared to the other two forms. At the time of estimate, the CC spending is part of AC, which also accounts for the project's actual expenditure. For the early stage estimate, $1,300,000 of the contingency budget is spent compared to $630,000 and $250,000 of Form #1 and Form #3, respectively. On the contrary, the Model Form #3 has the lowest CC consumption, while Form #1 implies the average of the consumption during all stages of the project duration. While the Ω is the same for all the three forms, it is the CC factor that differs. Such a difference is based on the difference in the CC spending behaviors and is related to the three different rates of CC consumption. The three rates (as presented in Figure 1) rule the amount of CC spending. With this regard, the column ContEAC in Table 2 shows the contingency estimate at completion, defined as the total contingency budget spent by the end of a project. This estimate is also based on the rates of CC consumption and is compared to the total CC budget of $2,900,000 set as a fixed percentage during the project planning phase. In addition, the Model Form #2 generates the most accurate forecasts of both the final contingency and the cost in the mid and late stages of the project life.

Model Form #2 also yields better CEACs for the mid-loaded family of projects in all three forecast stages than Form #1 and Form #2. As an example, for the early stage estimate PEs equal 0.03%, compared to -1.08% and -1.78%, respectively. With regard to the estimate of ContEAC Model Form #3 produces more accurate estimate with its PE of 1.95% in the early stage and Form #2 in the mid and late stages.

For projects where most of work is planned to be executed in the second half of their life, Model Form #3 generates the most accurate CEACs in all three estimate stages. For such back-loaded projects Form #3 fits better its S-curve and the contingency spending behavior, which is represented by its CC factor √Ω. This implies that the CC consumption rate is the lowest at the beginning of the project life compared to those of the other two forms. The rate then increases steadily as per the factor's 2nd derivative reaching its highest value by the project end. The values of ContEACs are more accurate when they are computed by Model Form #3 in the early and mid stages and by Form #2 in the late forecast stage.

5.2 Choosing the Right Form Based on an S-curve and Contingency Spending Behavior

The results of this study revealed that the accuracy of CEACs computed using the three model forms differs depending on the project family, represented by an S-curve, and CC consumption behavior.

If a project's S-curve is right-skewed and most of the work is planned in the first half of its life, then it is suggested that Model Form #2 with its Equation 7 is used to estimate the risk adjusted CEAC. In fact, this form produces the most accurate CEACs. Also, in such projects project managers may expect that the greatest portion of the risk is born early in the project when most of the work is planned and executed, as exemplified in Figure 2. Accordingly, project managers would tend to spend most of contingency budget with its maximum rate during the project's early stages and the CC expenditure will be decreasing as far as few activities are remaining. Also, the demonstration of the framework model to the notional EVM dataset showed that in such projects the cost accrual rate (also the peak spending) is also the greatest at the project's early stage (30% into its life in Table 3), which is found by the nonlinear fit of the GGM. Model Form #2 can also be used for mid-loaded projects when the shape of the cost S-curve line is symmetric with respect to the project duration: for this family of projects, it yields better risk adjusted estimates. The considerations relevant to front-loaded projects can also be pertinent for this type of projects. However, even if CCR is decreasing and not the highest at the mid of the project life (i.e., to proportionate to cost S-curve peak) the most of the contingency budget is spent as the decrease rate is sharp. This implies that project managers aggressively address risky events to resolve them as early as possible. Graphically, the form's curve with the CC factor Ω^2 represents such managerial behavior and same fast decrease in the CC spending rate, as presented in Figure 1.

The Model Form #3 is used for back-loaded projects as it better captures the CC consumption behavior and, therefore, produces more accurate risk adjusted estimates. In such projects, most of the work is planned for the second half of their life and project managers may expect that most of the risk burden will fall accordingly at this stage. In such projects, the work done accelerates after the projects' mid life and the CCR increases and reaches its maximum value as the project closes to its end. Project managers spend the contingency budget according to the form's factor √Ω, gradually increasing the rate and speeding it up after the mid life (represented in Figure 1).

As a final note, when compared to the other two forms, Form #1 generates the least accurate CEACrisk results. The assumption for this form is that CCR is constant and proportional to spending the BAC (the CC factor Ω), which is ruled by the GGM in the estimation process. With such a finding it is suggested that the CC consumption profile should not be solely dependent on the S-curve pattern of a project.

6. Implications and Future Research

The study originates both theoretical and practical contributions to the body of knowledge and the field.

As a theoretical contribution, the research bridges the gap between the EVM based cost forecasting and CC management, that are traditionally being regarded as two separate streams of the project management research, and brings them together into a comprehensive model. So far, these two research streams have rarely been addressed in tandem and no study is available to mathematically represents both theories into a model to help forecast risk adjusted CEACs. In particular, the proposed framework model is a modification of the original CEAC model by Narbaev and De Marco (2014). The original CEAC model (Equation 1) calculates the expected cost for the project's remaining work with the GGM via nonlinear regression curve fitting. This study considerably modifies and extends it by adding a new component reflecting the CC spending in CEAC calculations in a way that future risk is accounted into past performance based estimates. Therefore, the proposed risk adjusted CEAC framework model achieves its theoretical objective which was to combine the EVM cost curve with the CC consumption curve to produce risk adjusted final cost estimates.

From a practical point of view, the proposed model can be regarded as a useful framework for project managers that can use any of its three forms (formulae) to compute risk adjusted CEACs. The model's forms are able to capture the main CC spending categories of project managers' behaviors and the choice of a particular form depends on two main considerations: the universe of projects grouped into three families and risk attitudes grouped into three categories. First, the choice of the appropriate formula is based on the selection of the universe of projects grouped into front-loaded, mid-loaded, and back-loaded and represented by right-skewed, symmetric, and left-skewed S-curves, respectively. Second, the choice can be made between three different attitudes that project managers have in spending CC of their projects to respond to uncertainties as part of effective risk management. Each attitude is represented by a different CC consumption rate, which can be either constant, decreasing, and increasing along a project life. In other terms, project managers and teams managing large projects for governments and main contractors can use to model to test ex-ante the effects of different risk policies, namely to figure out possible CEACs resulting from application of either a risk-preventive, risk neutral, or risk-reactive attitude.

With this regard, future research can be directed towards understanding whether the three proposed profiles may improve the range of cost estimates for various categories of real projects with risk-preventive, risk-neutral, or risk-reactive managerial attitudes. However, in particular, this work opens roads to future research that can be related to validation of the model with real project data, application of the model in different projects with corresponding different risk behaviors, and testing for the responsiveness and timeliness in the accuracy of the CEAC estimation. However, this would need an ex-ante understanding and definition of the type of risk attitude of the project team. The framework model may also be applied to various industries and field projects.

7. Conclusion

This paper proposes a model that accounts for CC spending throughout the project execution and represents it in risk adjusted CEAC formulae and calculations. The model represents the process of CC spending as an intrinsic factor of project performance in calculating CEACs. The usage and viability of the model is demonstrated with an EVM dataset that represents the three categories of the universe of projects with cost contingencies spent at three different consumption rates. The framework model requires the availability of EVM metrics such as PV, EV, AC, and BAC and the usage of nonlinear regression modeling to compute the variables of the model equation.

All in all, the framework model reveals the cost-schedule-risk relationship in cost forecasting. In particular, EVM accounts for cost and schedule measures in the model while CC management considers risks. Such a connection is achieved through capturing the dynamics between a cost baseline and contingency accounts for forecasting risk adjusted final cost during project execution.

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