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Improving Earned Value Forecasting through Integration with Risk Analysis and Scope Change Management

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Abstract: Cost overruns on construction projects have long been an issue for owners. Accurate prediction of completed project costs allows owners to better plan for the eventualities, such as obtaining approval for a budget increase, establishing financial reserves, or taking steps to control the overrun. Earned value techniques are commonly used for such forecasting. This approach invariably utilizes past performance indices and/or predicted future performance indices to calculate the cost at completion. What is often neglected from the analysis is how risk events, pending change orders, and potential claims will impact that cost. Risk analysis techniques are commonly used to quantify uncertainty in project costs at the outset of the project to develop a contingency fund. This process can be extended into the construction phase of a project to help predict final cost. This study demonstrates how traditional earned value forecasting techniques can be integrated with risk analysis techniques to improve an owner's ability to predict and mitigate cost overruns.

1 INTRODUCTION

The construction industry is well acquainted with project cost overruns. Literature has shown that cost growth on construction projects has historically been in the area of 20-30% (National Defense Industry Association - Program Management Systems Committee (NDIA-PMSC), 2011). The environment in which construction occurs is filled with uncertainties such as weather, market conditions, labour productivity, material availability, etc. and project management is often left to make projections on final project costs as construction progresses. A commonly used tool to provide these projections is earned value management (EVM) forecasting. EVM is a management tool that compares physical construction progress against planned progress and actual costs, and from this comparison, calculates an Estimate at Completion (EAC). The EAC is traditionally based on past cost performance; however, different variations on this approach have been proposed in literature to use adjusted cost performance indices, or schedule performance indices. A downfall with this form of EVM forecasting is that it fails to account for risks or the pending costs related to scope change or clarifications that are currently in process. Although this idea is not new to project management fields, the objective of this paper is to demonstrate a process for improving EVM forecasting by integrating it with risk and scope change management forecasts. This integrated EVM forecasting is then used to calculate a new EVM performance index that guides management's attention more accurately to the problem areas.

2 REVIEW OF CURRENT PROCESSES

2.1 EVM

"EVM is a management methodology for integrating scope schedule and resources; for objectively measuring project performance and progress; and for forecasting project outcomes" (P. 5, Project Management Institute, 2011). EVM was first introduced in the project management environment in 1967 by the US Department of Defense through the Cost/Schedule Control Systems Criteria (C/SCSC)

(Fleming & Koppelman, 2006), and subsequently expanded into the entire project management field. For brevity, this paper will focus the literature review on the forecasting component of EVM. The reader is referred to Project Management Institute (2011) and Fleming and Koppleman (1994) for information on EVM fundamentals.

The traditional EVM forecasting equation is used to determine the EAC by dividing the budget at completion (BAC) by the latest Cost Performance (CPI) (Shtub & Bard, 1994), as shown in the equation below:

[1] $$\mathrm{EAC} = \frac{\mathrm{BAC}}{\mathrm{CPI}}$$

The downfall with this formula is that it was based only on past cost performance and assumed that future performance would be the same. Christensen (1993) conducted a review of a large number of EVM forecasting techniques and proposed a more generic forecasting equation:

[2] $$EAC = AC + \frac{(BAC - EV)}{index}$$

Where: AC = actual cost, BAC = budget at completion, EV= earned value, and Index = the performance index used to forecast future performance.

The Index in this equation was proposed to be any one of following, depending on type of work-package: CPI, SPI, CPI*SPI, or (w_1*CPI +w_2*SPI). The common weights for the later index are 0.8 for w_1 and 0.2 for w_2 (Project Management Institute, 2011).

Alshaibani (1999) introduced the additional forecasting performance index that accounts for future improvements in the equation. The approach uses the same forecasting formula proposed by Christensen (1992), and modifies the forecasting index using the following equation:

[3] $$Forecasting\ index = (\propto \% + CPI)$$

Or

[4] $$Forecasting\ index = (\propto \% + CPI)(\propto \% + SPI)$$

Where: $\propto \%$ is between 0 and 100 and is used to show the improvement to CPI or SPI that is expected. These forecasting equations improved upon the traditional method and allowed for forecasts to be better customized to particular project circumstances. Where they still fell short was their neglect to include project risks or pending items related to scope changes or clarifications.

2.2 Risk Management

Along with EVM, risk management for construction projects is also an often used tool for managers to predict future cost. It involves identifying risks (or opportunities) that could potentially impact the project and quantifying those impacts based on probability and magnitude (Project Management Institute, 2000). Since risk management is essentially the study of certainty, a growing trend in the field is to employ Monte Carlo simulation to the risk quantification process. This Monte Carlo simulation makes use of probability distributions in place of static values to model the possible distribution of outcomes (Palisades Corperation, 2010). The output of this form of risk analysis is a forecast of the remaining cost uncertainty on the project that is often added to the current budget to form an estimate at completion. The process is often undertaken by a separate project team, and then EVM and its results are viewed in some degree of isolation from the risk management results. This method is not new; techniques for integrating EVM and risk management have been explored in literature and practise: Association for Project Management (2008), Project Management Institute (2011), Narbaev & De Marco (2011), National Defense Industry Association (2011), Program Management Systems Committee (2011), Northrop Grumman Corporation (2007), Risk Decisions Ltd. & BMT Sigma Ltd. (2003).

3 INTEGRATION OF RISK MANAGEMENT AND EVM

A white paper prepared by Risk Management Working group of the National Defense Industrial Association (NDIA-PMSC, 2011) created a business case for integrating risk management processes with EVM. Following this, the NDIA EVMS application guide (National Defense Industry Association, Program Management Systems Committee, 2011) was created which also integrated risk management with EVM. The document clearly states that the two processes should be integrated, and provides high level flow charts on how and where this integration should happen through both risk and EVM processes. A key feature of interest to this application guide is the portion that deals with cost forecasting. It specifically states that risk is to be included in the assessment of estimate at completion for each WBS control account. However, it does not specify how this is to be done.

The PMI practise standard for earned value management similarly touches on the integration of risk management and earned value management in the development of the cost and schedule baseline, in the monitoring of risk mitigation plans, and provides the same risk and EVM process table as NDIA (2011), with the requirement for risk is to be included in the assessment of estimate at completion. In a book dedicated to interfacing risk and EVM, the Association for Project Management (2008) proposed an equation for performing this integration, where the EAC for the project is determined by adding the EAC for specific and non-specific risks to the EVM forecast. What is not touched on, however, is the link between the change management processes that will have an impact on the final cost estimate, but have not yet been worked into the EVM baseline because they are still in progress.

4 SCOPE CHANGE MANAGEMENT

Scope change management is one of the process groups in the Project Management Body of Knowledge (Project Management Institute, 2000) which involves the processes of initiating, defining, tracking, approving, and applying changes to the contracted scope of work. In the authors' experience, these processes can include:

- Notice of proposed change: the owner initiated process that communicates a potential change that may be coming in the future. This process allows a preliminary quantification of the proposed change as well as time to make necessary adjustments to prepare for such a change, should it occur.
- Proposed innovation: a process that allows the contractor to suggest changes to the proposed design that would show benefits in cost, schedule, and/or quality.
- Site instructions: the engineer initiated process that provides direction for minor changes or clarifications to the contracted work that are usually of a more immediate nature. Often, additional costs for these instructions will come at a later date, after the work has been completed.
- Change orders: the final step in the change management process. This is the only process that can approve changes to the contract budget or schedule. Although, at times, it is more of a formality, since the previous processes will essentially finalize the change.

What has been found in construction projects is that these processes often fall behind. Site instructions can be issued to the contractor, but the associated cost is not communicated back until months after the work is completed, or pending notice of proposed changes that may or may not occur could be left in limbo for extended periods of time awaiting approval. Items such as these are tracked on scope change management logs, but their potential impacts to the project are not accounted for in the EAC because it is either unknown or not integrated with the EVM or risk management processes. This potentially leaves millions of dollars in pending scope changes unaccounted for in the project EAC.

The ideas discussed in the following study aim to fill this void by defining a process integrating scope change management with risk management processes and then tying this information into the EVM forecasting in order to produce a more realistic and robust EAC and a new EVM performance index.

5 PROPOSED APPROACH

The first step in improving the EAC is to develop a process diagram that shows the base level of integration between the three processes: EVM, risk management, and scope change management. This is depicted in Figure 1.

As depicted in node 1, it is essential that all three processes link all information to the control account level which should be established at the outset of the project during WBS development. Each process should then periodically (monthly) update the information based on the latest status (node 2a, b, c). The EVM process then proceeds through the basic calculations (node 3a, 4a), but as this is happening, the risk and change management processes must integrate their information to allow the risk register to include those items which have a potential cost impact to the project, but are unconfirmed (node 3b). Risk management is best suited to convert these items to risks and quantify them accordingly. Once the register is updated and properly linked to control accounts, a joint calculation is undertaken between risk and EVM processes where risk and the schedule-performance-adjusted EAC are simulated to give an integrated EAC distribution. The equation used combines equation [2] and [4] and adds risk exposure (summation of probability multiplied by impact of each risk) and pending changes exposure (summation of probability and impact of all pending changes):

[5]
$$Integrated\ EAC = AC + \left(\frac{BAC - EV}{0.8 * CPI + 0.2 * SPI}\right) + \sum Risk\ Exposure + \sum Pending\ Changes\ Exposure$$

The forecasting index used in this equation makes use of the schedule performance as this is considered to be an indicator of productivity and delay claim risk. To avoid double counting this risk is it recommended that delay claim risks be removed from the risk simulation. Note that since schedule-performance-adjusted EAC in this circumstance is a static value, it could be added to the risk simulation after the fact; however, including it into the simulation will produce a complete EAC distribution and gives the opportunity for possible simulation of the schedule-performance-adjusted EAC using ranges for the earned value and the performance index (but this is outside the scope of this paper). The EAC now being in the form of a distribution, and including risks and pending scope items, gives management a more holistic view of the EVM EAC.

The final step in the new process is to calculate a new EVM index that is used to communicate to management the true health of the project budget. The proposed index is coined “budget health index” (BHI), and is calculated using the equation:

[6]
$$Budget\ Health\ Index = \frac{Integrated\ EAC}{BAC}$$

If the index is less than 1.00, it shows that the current BAC used in the EVM calculations is over budget and vice versa if the index is over 1.00. For example, a typical project holding a 10% management contingency on top of the BAC could be in distress if this index dropped below 0.90 (projecting more than 10% above BAC).

In order to further demonstrate the benefits of this integrated approach to EVM forecasting, a sample project was created and will be discussed below.

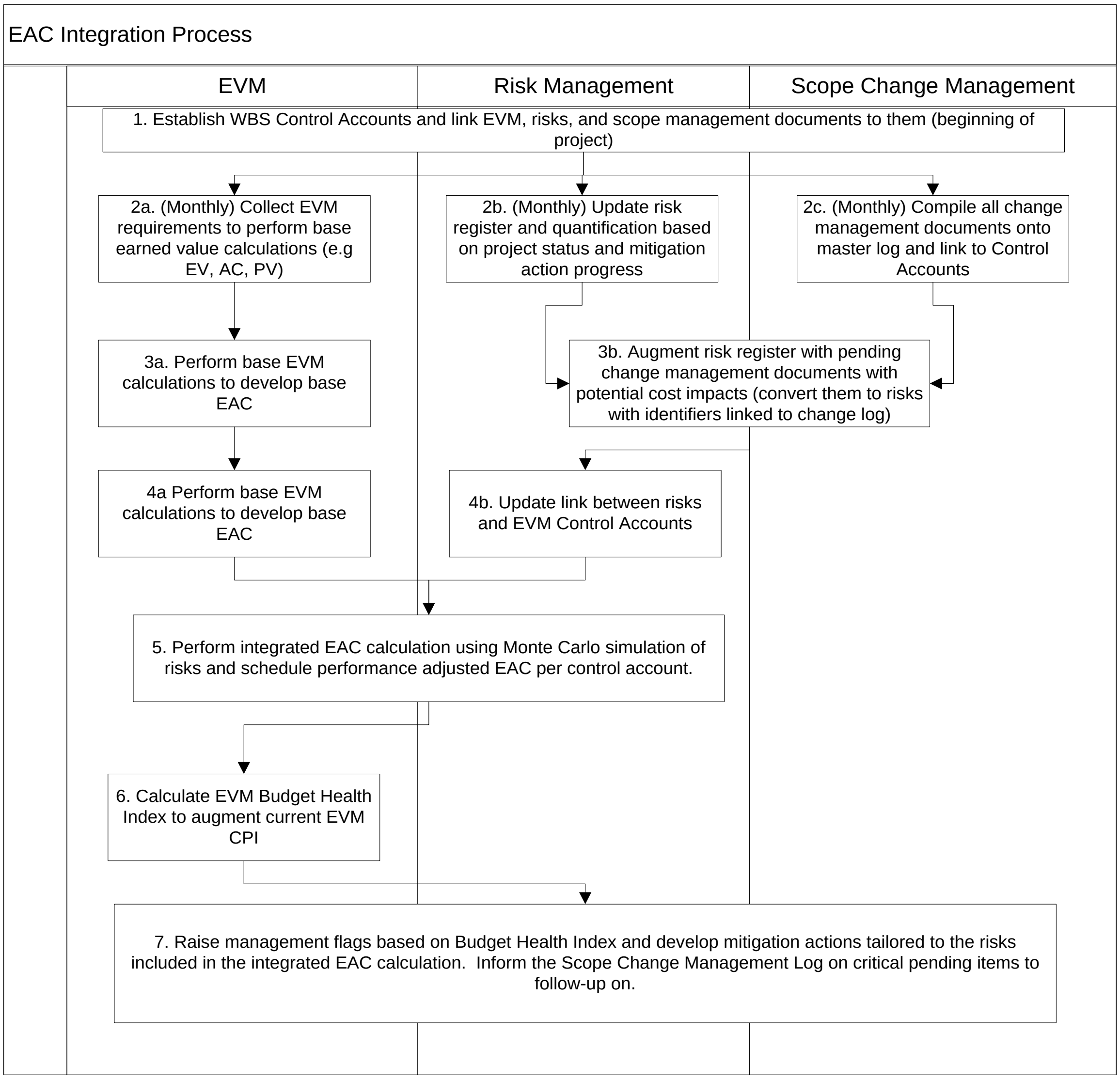


Figure 1: Proposed EAC integration process

6 SAMPLE PROJECT

The sample project has a BAC of $550,000 and a 10% contingency, giving a total project budget of $605,000. The EVM is performed monthly and any work-packages showing a variance of greater than 10% raise a flag for management attention. The sample is shown in two stages, the first is titled the "current approach" and uses traditional EVM, risk management, and scope change management processes, the second is the "proposed approach" as discussed in the previous section.

6.1 Current Approach

6.1.1 EVA

The traditional EVM calculation for the sample project is shown in Table 1. This example uses the traditional forecasting equation (Equation 1).

Table 1: Sample project earned value analysis (EVA) after 5 of 10 periods have lapsed

WBS Task	Traditional EVA								
	Budget at Completion	Progress	AC	PV	EV	CPI	SPI	EAC	VAC
WP A	$170,000	95%	$175,100	$170,000	$161,500	0.92	0.95	$184,316	-$14,316
WP B	$250,000	40%	$120,000	$155,000	$110,000	0.92	0.71	$272,727	-$22,727
WP C	$130,000	15%	$20,100	$25,000	$21,450	1.07	0.86	$121,818	$8,182
Project	**$550,000**							**$578,861**	**-$28,861**

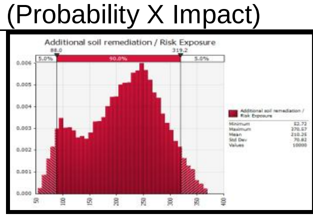
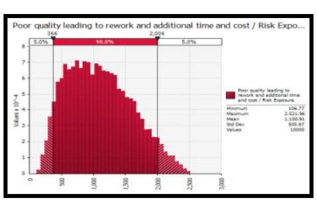
In this table, calculating the EAC per work-package and then adding this to the project level, the EAC comes out to $578, 861, a $28,861 overrun from the current budget at completion. Assuming this project has a total budget of $605,000 (including a 10% management reserve ($55,000)), the project would still be on track to fall within the total budget. If we look at each individual work-package, and assume that management attention would be initiated if the Variance at Completion was greater than 10% of the BAC, no packages would raise a flag. Each package has a CPI within a 10% variance.

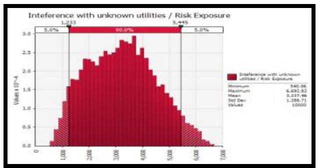
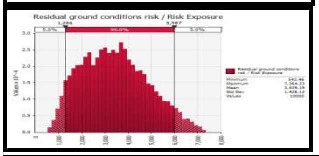
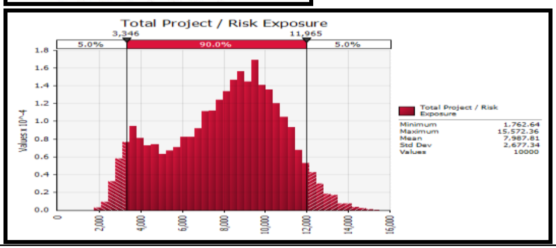
6.1.2 Risk Management

The same project has a risk management process that has the key risks for each package compiled onto a risk register, as shown in Table 2.

The total risk exposure updated to the latest period would be taken from the risk distribution shown in the table. If the mean value of $7,988 were used for decision making, and risk and EVA were not integrated, management would not be alarmed because the exposure is within the management reserve of $55,000.

Table 2: Sample project (abbreviated) risk register

Risk Register			
Risk Descriptor	Risk Exposure (Probability X Impact)	Risk Notes	Work-package
Additional soil remediation		Residual risk identified at beginning of project for additional soil remediation work above and beyond that already planned for. Estimated impact is an increase to current remediation work ($10K) by 10-25%. Probability is “unlikely” considering the geotechnical investigation results and current progress showing good ground.	A
Poor quality		First quality checks have shown good results. Reduced original probability to “unlikely” to account for this.	A

Interference with unknown utilities		This risk accounts for running into utilities during construction that have not been identified and accounted for in the plan. About half of the work is complete and no issues have arisen related to this risk. Probability reduced to "unlikely".	B
Residual ground conditions risk		Remaining unknown ground condition issues that could lead to additional change orders.	C
Total Risk Exposure			

6.1.3 Change Management

Again, the same project also has a change management process that tracks the change forms that have been issued. An example is shown below. Only work-package A items are shown for brevity, although the other packages would have similar items. This table would be used to track the status of the forms. Typically, only those items that have become change orders would have an associated cost tracked on the form. These costs can often be neglected from any calculated forecast of costs until they become an official change order, and usually only after that change order has been approved, so they then become part of the EAC (because they get integrated into the budget at completion). Items like site instructions or notices of additional costs would remain on the register, with unknown cost consequences until these costs come in from the contractor. These may also be considered too detailed to become risks on the risk register. As this change management table grows, especially on large projects, it can become very significant and still not be included in the EAC.

Table 3 - Change Management Register for sample project

Change Management Register				
Form	Notes	Costs	Status	Work-package
Notice of additional cost #2 - excessive ground moisture	Contractor submitted notice of additional cost for excessive ground moisture.	Unknown	Pending	A
Change order #3 - changed code requirements	Code requirements for compaction changed after contract award. Change order passed engineer's approval only awaiting owner sign-off and approval of costs.	$7000	Pending	A
Site instruction #2	Site instruction to extend curb to end of walkway. Contractor completed work but cost of work has not been indicated.	Unknown	Issued to Contractor	A

6.2 Proposed Approach

6.2.1 EVA Integration with Risk of Delay Claim/Costs

The first change in integrating risk with EVA is to add the schedule performance into the EAC equation. This schedule performance is a factor in the project's exposure to delay claims from the contractor.

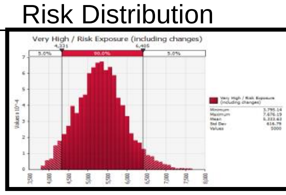
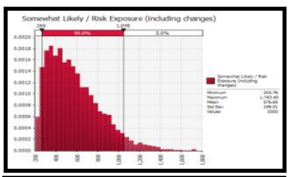
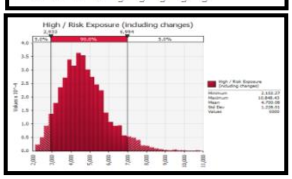
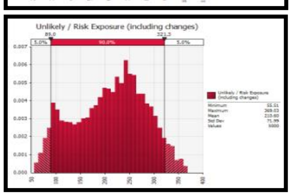
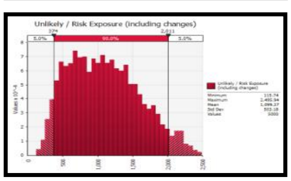
Literature shows that a good value to use to capture the link between schedule delay and cost increase is 20% SPI and 80% CPI to determine the forecast (Project Management Institute, 2011). This is a good value to use for schedule performance to account for a significant, but not one-to-one correlation. The equation in this case is:

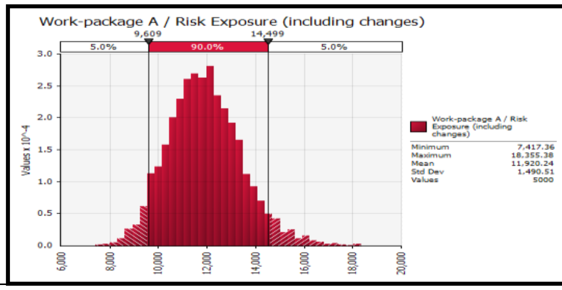
[7] EAC = AC + (BAC - EV) / (20%*SPI + 80%*CPI)

6.3 Risk Management Integration with Change Management

In the previous example, risk was accounted for at the project level, and change management was independent of risk management with potentially important cost items left with unknown costs impacts. An important component of the integrated EAC proposed in this study is linking the change management and risk management processes. This is essentially done by using the change management register to inform the risk register. All items on the change management register are reviewed by risk management and any items with associated costs are added to the risk register. As they become risks, they are investigated more thoroughly to determine the likelihood of the costs arising, and the range of values the final cost could come out to be. This is shown in Table 4.

Table 4: Work-package A risk analysis and change management integration

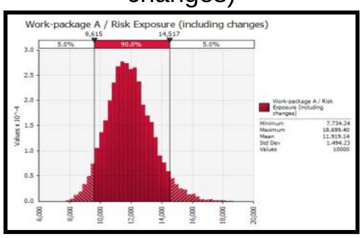
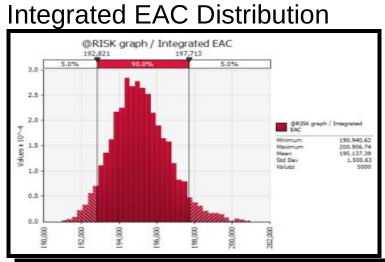
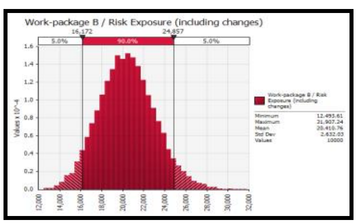
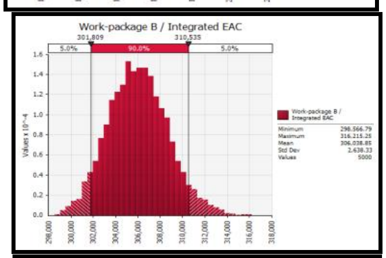
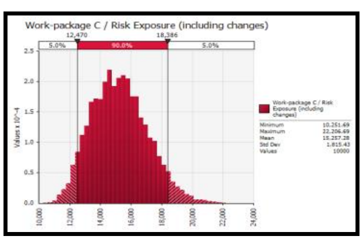
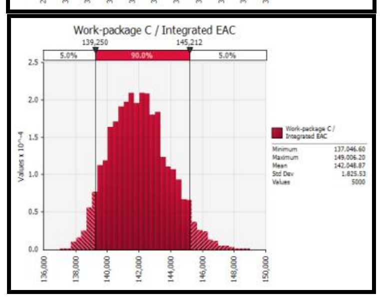
Work-package A	Risk Distribution	Notes
Pending change order #3		Change order passed engineer's approval only awaiting owner sign-off and approval of costs.
Site instruction #2		Engineering anticipates $0K cost, but contractors estimate still uncertain. There is a 25% chance of cost coming from contractor in the order of $1000 to $5000 (closer to low end of cost).
Notice of additional costs #2		Contractor submitted notice of additional cost for excessive ground moisture. Engineer's stance is this is the contractor's risk. Probability is high, costs estimated based on incremental increase in compaction work and ranged plus/minus 50%.
Risk: additional soil remediation		Residual risk identified at beginning of project for additional soil remediation work above and beyond that already planned for. Estimated extent is an increase to current remediation work ($10K) by 10-25%. Probability is "unlikely" considering the geotechnical investigation results and current progress showing good ground.
Risk: poor quality		Schedule is not an issue for this task (50 days of float) and this indicates that quality will be less of an issue (not rushed to completion). Reduced original probability to "unlikely" to account for this.

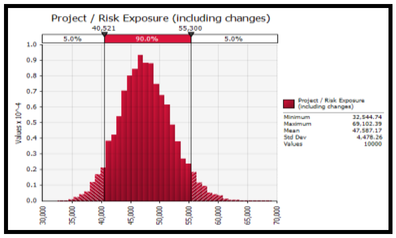
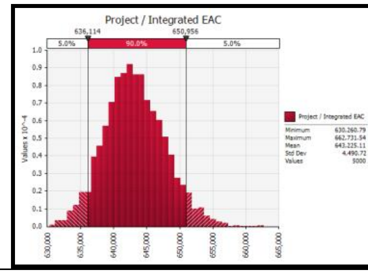
Total risk exposure (including change management items)	

6.4 Integrating EVA Forecast with Risk Exposure for EAC at Work-package Level to give Integrated Performance Index for Control Purposes

The final change is to integrate the EVA EAC with the new risk analysis results for each work-package. The result is an integrated EAC which includes the EVA, risk management, and change management components. An example is shown in Table 5.

Table 5: Integrated EAC approach (expected values shown)

WBS Task	Integrated Approach		
	EAC (with SPI included)	Risk Exposure (including changes)	Integrated EAC Distribution
Work-package A	$183,216		
Work-package B	$285,627		
Work-package C	$126,788		

Project	**$595,631**		

The results of this integration show that when all the available information related to cost is integrated into the EVA forecasting, the total EAC is more accurate and informative then seeing all the results individually (seeing EVA forecast, risk allowance forecast, and change management log separately). In this example, the integrated EAC mean value is $643,218, a $93,218 or 17% overrun of the current BAC. Using the same assumption of 10% contingency on this project, this projected overrun is much more alarming then the current EVA forecasting approach which projected to fall within the total budget. This demonstrates that the proposed approach more closely reflects reality then the traditional EVM approach.

Table 6: Summary comparison between current approach and the proposed integrated approach.

Work-package	Current Approach			Integrated Approach (Mean Values)		
	CPI	EAC	VAC	Integrated Performance Index	Integrated EAC	Integrated VAC
Work-package A	0.92	$184,316	-$14,316	0.87	$195,136	-$25,136
Work-package B	0.92	$272,727	-$22,727	0.82	$306,037	-$56,037
Work-package C	1.07	$121,818	$8,182	0.92	$142,046	-$12,046
Project	**0.95**	**$578,861**	**-$28,861**	**0.86**	**$643,218**	**-$93,218**

The additional index that is proposed to augment the new integrated approach is an integrated performance index. This index is based on dividing the project BAC by the integrated EAC. It allows instant feedback on actual cost performance to the end of the project. This index provides more insight than the traditional CPI because it is based on a holistic look at the final project cost based on all potential contributors: past cost performance, past schedule performance, risks and change management projections. The traditional CPI only demonstrated past performance. In the example, the integrated performance index for each work-package would raise a flag for management attention because each shows greater than 10% variance. As shown previously, the current approach would not have raised any flags (less than 10% variance shown).

7 CONCLUSIONS

In this study, traditional EVM techniques for forecasting final project costs on construction projects are assessed and improved by integrating the risk management and scope change management processes into EVM forecasting to produce a more robust and realistic estimate at completion. EVM, risk management, and scope change management are all best practises for construction projects and contain valuable and unique information related to the estimate at completion. This study builds off of past literature related to integrating risk with EVM, identifies the need to include scope change management processes (particularly those in the form of site instructions and notices of proposed changes) and offers a process diagram to propose the nodes of integration between the three processes. By informing EVM forecasting in this way, a new equation is derived to come to a more robust and realistic EVM estimate at completion. The calculation uses Monte Carlo simulation of the updated risk register along with a schedule-adjusted EAC equation to offer a distribution of the estimate at completion. Additionally, a budget health index, come to by dividing the new integrated estimate at completion by the EVM budget at completion, is offered to augment the traditional cost performance index. The budget health index provides feedback on the true cost performance of the project, allowing management attention to be better focussed. The added benefit of this approach is that the corrective actions initiated by the EVM results can make use of the risk mitigation actions on the risk register. In reference to further research on this topic, it is noted that significant opportunity exists to build off of this study by adding simulation of EVM indices in the proposed EAC calculation.

In conclusion, the proposed approach to forecasting project costs contributes to the accuracy of EVM through integration with risk and scope change management forecasts. It produces more informative results that can be relied on for key management decisions such as: (1) increasing owners' confidence for when contingency can be released; (2) allowing owners to plan ahead for likely cost increases (e.g. governmental approvals for further funding); and (3) allowing owners to mitigate potential increases by making necessary decisions.

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