ENHANCED EARNED VALUE MANAGEMENT ON PRACTICAL CONSTRUCTION PROJECTS THROUGH CONSTRAINED PROJECT SCHEDULING SIMULATIONS

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ABSTRACT

The Earned Value Management (EVM) techniques are commonly used for tracking construction project cost and schedule performances. The work completed on activities in the project network model is quantified to provide a basis for comparing as planned and actual performances in terms of time and cost. The aim is to detect any cost and schedule deviations and take timely corrective measures so as to control project delivery under budget and ahead schedule. However, it is not straightforward to apply EVM to track and control practical construction projects, subjected to tight constraints on technology, resource and space. This research is mainly focused on applying EVM on constrained (resource and calendar) construction scheduling subject to activity delays and project time extensions in order to reveal EVM limitations. A geotechnical investigation construction project provides a case for defining problems and formulating solutions. The results prove that the EVM does not well account for total float, project time extension and non-productive cost in practice; while, the forecasting technique used in EVM is insufficient to detect any delays that occur and cause project time extension and cost overrun on the project. This research has formulated project scheduling simulations which enhance EVM and facilitate its applications by conducting precise schedule and cost analysis in support of the EVM. As such, project managers can effectively track, monitor and control project status as the construction progress unfolds continuously.

KEYWORDS

EVA, performance index, scheduling, total float, project time extension, cost overrun.

INTRODUCTION

Tracking cost and schedule are vital in managing a project. The Earned Value Management (EVM) is widely employed to get the better insight of cost and time performance requirements (McConnell 1985). However, the Earned Value Analysis (EVA) is difficult and challenging as the scheduling data are time-dependent (Eldin 1989). Christensen (1993) reported that the EVA accuracy depends on the contract stage; and the EVA indicators are confusing if the project lacks accurate information such as fully documented scope, schedule and cost estimate (Lukes 2008). Thus, the EVA may fail to obtain representative indicators, more often, misleading. Previous researches improved the EVA by integrating factors such as product performance, customer satisfaction and risk management (Solomon and Young 2007); developing forecasting methods that take into account the project duration uncertainties (Kim and Reinschmidt 2010).

A precise resource- and calendar-constrained construction schedule is crucial. PMI (2005, 2008) defined the EVA without in-depth considerations of schedule constraints. This imposes complexities in applying the EVA. In this paper, the resource scheduling analyses are enabled by using prototyped computer software Simplified Simulation-empowered Scheduling (S3) accompanied with the mainstream Primavera Project Planner (P3). The underlying schedule simulation engine of S3 employs the discrete event simulation techniques (SDESA by M. Lu in 2003). Previous research (Lu and Lam 2008) proved that S3 is capable to accurately schedule and analyze highly constrained construction schedule network.

This research is aimed at applying EVM on constrained construction scheduling in order to reveal EVM limitations and performance indicator deficiencies. This paper firstly introduces the EVA terminologies, followed by defining the “Project Time Extension (PTE)” and “Productive and Non-Productive Cost” for project time and cost estimations. A geotechnical investigation construction project was used to investigate the enhanced EVM feasibility and conclusion is drawn based on the findings.

EARNED VALUE ANALYSIS TERMINOLOGY

The Earned Value Analysis (EVA) is aimed at integrating work, cost and schedule (PMI 2005). Three parameters, Planned Value (PV), Earned Value (EV) and Actual Cost (AC), lay the EVA foundation (Figure 1). PV is the budget cost planned to be spent during project execution; EV is budget cost based on the work performed. (Analytically, EV is calculated by activity budget, including direct cost and indirect cost, multiplying the percentage of work completed); AC is actual cost of completed works. During the tracking time (Data date), the records of "Completed Activity", "Incomplete Activity" and "Completion Percentage of Processing Activity" are updated. The Cost Variance (CV), Schedule Variance (SV), Cost Performance Index (CPI) and Schedule Performance Index (SPI) can be calculated (Table 1). These parameters indicate the project cost and schedule performances. Negative CV or CPI less than one implies project status being under budget; while positive SV or SPI less than one means ahead schedule.

The EVA enables forecasting by projecting current project performance to the project completion date. Budget At Completion (BAC), Estimate To Completion (ETC), Estimate At Completion (ETC) and Variance At Completion (VAC) are related indicators. BAC is the budget planned to be spent in completing the project (mathematically, summation of PV). ETC is the predicted expenses to complete the project with different assumptions (Table 3). Thus, the VAC, which is the indicator of future project cost performance, with negative value implied that the project cost overrun likely to occur upon project completion and vice versa.

The To-Complete Performance Index (TCPI) indicates the productivity trend (Table 4). TCPI can be calculated based on EAC or BAC. Often, construction projects usually span over years and over budget, $TCPI_{ETC}$ is usually chosen for the analysis. The value greater than 1 indicates an increase in project productivity. Based on EVA indicators introduced, planners could monitor and forecast the project performances by implementing EVM.

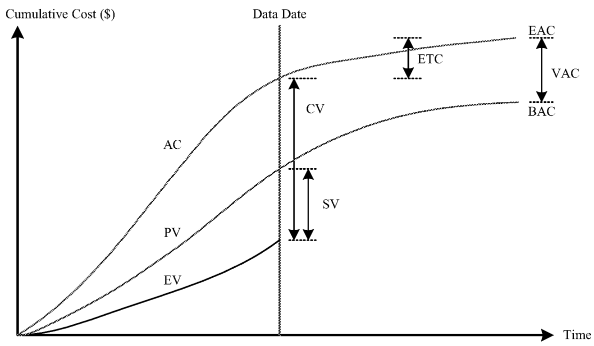

Figure 1 EVA parameters overview

Table 1 EVA Basic Formula

Indicator	Formula
Cost Variance (CV)	EV – AC
Schedule Variance (SV)	EV – PV
Cost Performance Index (CPI)	$\frac{EV}{AC}$
Schedule Performance Index (SPI)	$\frac{EV}{PV}$

Table 2 EVA Forecasting Formula

Forecasting Indicator	Formula
Estimate At Completion (EAC)	AC + ETC
Estimate To Completion (ETC)	EAC – AC
Variance At Completion (VAC)	BAC – EAC

Table 3 ETC Assumptions

ETC Assumption	Formula
Work performed at Budget Rate	BAC – EV
Work performed at Present CPI	$\frac{BAC-EV}{CPI}$
Work considering both CPI and SPI	$\frac{BAC-EV}{CPI \times SPI}$

Table 4 EVA Trend Formula

Forecasting Indicator	Formula
To-Complete Performance Index based on EAC ($TCPI_{EAC}$)	$\frac{BAC - EV}{EAC - AC}$
To-Complete Performance Index based on BAC ($TCPI_{BAC}$)	$\frac{BAC - EV}{BAC - AC}$

NON-PRODUCTIVE COST FOR COST CONTROL

In EVA, the activity costs are calculated based on the activity resource allocated. This assumes the resources (labors and equipments) are immediately released after activity completed and re-employed if necessary. In practice, laborers are hired till finishing all the tasks and the equipment is charged by day once stationed on site. To enhance the EVA analysis, the productive cost and non-productive cost are proposed to be used in estimating reasonable activity costs.

Total project cost composed of direct and indirect costs. The direct cost generally covers labor, equipment and raw material directly consumed. The indirect cost includes the expenditures on management, supervision and inspection. The total project cost (C_T) calculated as Eq. 1:

$$C_T = C_D + C_I \tag{1}$$

The direct cost (C_D) proposed includes the productive cost (C_P) and the non-productive cost (C_{NP}) as Eq. 2. Non-productive time implies the resources are idling. In EVA, the non-productive time and cost should be counted on the major resources such as laborers and essential equipment which are employed for the entire project (regardless of being busy or idling on site).

$$C_D = \sum_{i=1}^{N} (C_{P_i} + C_{NP_i}) \tag{2}$$

where N is the total number of resources

The indirect cost (C_I) is:

$$C_I = C_0 + D \times C_d \tag{3}$$

where C_0 is the project initiate cost or project contingency
D is the total project duration
C_d is the management cost per day.

In bidding, the indirect costs (overhead) are prorated to all activities in the project. However, in using EVA, separating the direct and indirect cost is necessary. This research emphasizes the non-productive cost in EVA indications.

TOTAL FLOAT (TF) AND PROJECT TIME EXTENSION (PTE) FOR TIME CONTROL

Previous research found that the TF breaks down when the constraints imposed (both resource and calendar constraints). De la Garza and Kim (2005, 2009) concluded that TF value with multiple calendars no longer held traditional definitions. Accurate TF value can be calculated by Resource-Constrained Critical Path Method (RCPM) (De la Garza and Kim 2005) or Resource-Activity Critical Path Method (RACPM) (Lu and Li 2003). Enabled by schedule simulations, S3 takes advantage to generate accurate constrained schedule by using RACPM (Lu and Lam 2008). The TF could be evaluated by "What-if" simulations. However, the TF does not insightful to represent the activity criticality under this complex scenario. The Project Time Extension (PTE) proposed to provide another view of activity criticality. The PTE value determines the project extension if an activity is delayed. For project time control, the Total Float (TF) and Project Time Extension (PTE) should be considered apart from the EVA indicators. The case study reinforces the methodology in using TF, PTE to support the EVA time control.

CASE STUDY ON CONSTRAINED CONSTRUCTION SCHEDULE

A geotechnical investigation construction project was used to investigate the EVA applicability in tracking project time and cost performances. The construction site was located at Tuen Mun Road (Tai Lam Section) in Hong Kong. This geotechnical investigation project consists of 25 activities. The project is composed of two boreholes and seventeen trial pit drillings, in-situ soil and sample testing. The contingency is $3,000 and the time-dependent indirect cost is $500 per day.

The project started on 21, August, 2009. The soil sample testing, activities 19, 20, 22, 24 are five-working days, while others are six-working days. The resource limits and resource calendars are given in Table 5. The activity resource allocations, costs, durations, are given (Table 6). The schedule computer software, Simplified Simulation-empowered Scheduling (S3) and Primavera Project Planner (P3), was employed in the schedule analysis. Same activity priorities were used in P3 and S3. It was found that the two systems generated schedules with identical activity logical sequence and total project duration. Hence, the two schedules were cross checked.

Time Control

The activity criticality could be regarded as the indicator of potential project time extension (PTE) as a result of activity delay. However, the TF values are greatly reduced in constrained schedule as mentioned. The P3 was found to generate the misleading TF values (comparing the TF columns in Table 7). Thus, the proposed PTE could provide another view of activity criticality. The PTE value of each activity is denoted in Table 7 column named "PTE (S3)". For instance, if activity 21 delayed *one* day after day 34 (its latest finish time), it leads to *three* days project time extension.

Cost Control

For cost control, the project cost reports were generated by S3 and P3 (Figure 2 (a) and (b)). The same value of BAC was generated ($223,960 equivalent to productive cost in S3). In addition, S3 was prototyped to accurately calculate the non-productive cost ($362,210) which P3 neglected. Thus, the BAC should be $633,670 (Productive Cost *plus* Non-Productive Cost) rather than $362,210.

LIMITATIONS IN TRACKING PROJECT DELAY

To prove the EVA fails to detect the project delay, the progress tracking continues with the activity "Backfill (REW4-TP)" updating. Three scenarios were done for the EVA analysis (Table 10). The first two scenarios implied the activity executed within TF. The last scenario depicted the activity delayed for one day. The activity completion percentages were recorded. For example, the activity was 95% completed after one day delay.

From the analysis (Table 10), the results proved that the TF and PTE could not be detected by using EVA. The increasing SPI implied the execution is ahead schedule with improvement. However, the activity becomes critical after consuming TF and delay 1 day would result in seven days project time extension without any EVA notifications. Thus, planners are recommended to observe the TF and PTE value along with EVA.

For cost control, the CPI generated by P3 is decreasing and indicating the project is under-budget with improvements. However, the S3 cost analysis shows that when there is 1 day delay, the project time extension creates extra indirect cost and the non-productive cost. The cost value (such as the AC, EV, PV and BAC) solely calculated by productive cost is ambiguous. Thus, it is proposed that the cost tracking should include the non-productive cost to get an accurate analysis. Further research should be conducted to integrate the non-productive cost with cost parameters to enhance the EVA, for the delayed schedule.

Table 5 Resource Requirements

Resources	Limit	Unit	$/Unit	Calendars
Analyst	-	No.	240	Monday – Friday
Drill	-	No.	220	Monday – Saturday
Institute	1	No.	50	Monday – Wednesday
Mobilizer	-	No.	4,500	Monday – Saturday
Operator	1	No.	1,000	Monday – Wednesday
Plant	1	No.	250	Monday – Saturday
Setup Equipments	1	No.	1,200	Monday –Saturday
SPT Test Equipment	-	No.	220	Monday –Saturday
Vibrator	1	No.	150	Monday –Saturday
Worker	6	No.	800	Monday –Saturday

Table 6 Activity Requirements

Activity ID	Activity	Predecessor ID	Planned Resource [Unit per day]	Planned Duration	Budget Cost	Actual Resource [Unit per day]	Actual Duration
1	REW4-BH1	3, 4, 5	Worker [3] Drill [5] Mobilizer [1] Operator [1] Setup Equipment[1] SPT Test Equipment[1]	4	41,680	Worker [3] Drill [8] Mobilizer [2] Operator [1] Setup Equipment[1] SPT Test Equipment[2]	2
2	REW8-BH1	1	Worker [3] Drill [5] Mobilizer [1] Operator [1] Setup Equipment[1] SPT Test Equipment[1]	3	32,580	Worker [3] Drill [8] Mobilizer [2] Operator [1] Setup Equipment[2] SPT Test Equipment[2]	2
3	REW4-TP1	ST	Worker [3]	5	12,000	Worker [4]	3
4	REW4-TP2	ST	Worker [3]	5	12,000	Worker [4]	3
5	REW4-TP3	ST	Worker [3]	5	12,000	Worker [3]	1
6	REW5-TP1	11, 12, 14	Worker [3]	3	7,200	Worker [3]	6
7	REW5-TP2	11, 12, 14	Worker [3]	3	7,200	Worker [3]	6
8	REW5-TP3	11, 12, 14	Worker [3]	3	7,200	Worker [3]	4
9	REW5-TP4	11, 12, 14	Worker [3]	3	7,200	Worker [3]	3
10	REW6-TP1	11, 12, 14	Worker [3]	3	7,200	Worker [3]	4
11	REW6-TP2	21	Worker [3]	3	7,200	Worker [3]	4
12	REW7-TP4	21	Worker [3]	3	7,200	Worker [3]	3
13	REW8-TP1	3,4,5	Worker [3]	3	7,200	Worker [3]	4
14	REW9-TP1	21	Worker [3]	3	7,200	Worker [3]	4
15	REW12-TP1	6, 7, 8, 9, 10	Worker [3]	3	7,200	Worker [3]	4
16	REW12-TP2	6, 7, 8, 9, 10	Worker [3]	3	7,200	Worker [3]	5
17	REW12-TP3	15	Worker [3]	3	7,200	Worker [3]	2
18	REW12-TP4	16	Worker [3]	3	7,200	Worker [3]	3
19	Testing (REW-BH1)	2	Analyst [1]	5	1,200	Analyst [1]	1
20	Testing (REW4-TP)	3,4,5	Institute [1]	6	300	Institute [1]	5
21	Backfill (REW4-TP)	20	Worker [2] Vibrator [1] Plant [1] Operator [1]	2	6,000	Worker [2] Vibrator [1] Plant [1] Operator [1]	3
22	Testing (REW5-9-TP)	6, 7, 8, 9, 10, 13	Institute [1]	6	300	Institute [1]	7
23	Backfill (REW5-9-TP)	22	Worker [2] Vibrator [1] Plant [1] Operator [1]	2	6,000	Worker [3] Vibrator [1] Plant [1] Operator [1]	3
24	Testing (REW12-TP)	17, 18	Institute [1]	6	300	Institute [1]	5
25	Backfill (REW12-TP)	24	Worker [2] Vibrator [1] Plant [1] Operator [1]	2	6,000	Worker [2] Vibrator [1] Plant [1] Operator [1]	2

Table 7 P3 and S3 Schedule Analysis Results

Act. ID	Act. Description	Duration	ES	EF	LS	LF	TF (S3)	TF (P3)	PTE (S3)
1	REW4-BH1	4	12	20	16	24	4	47	3
2	REW8-BH1	3	59	62	66	69	7	17	1
3	REW4-TP1	5	0	6	10	16	10	28	3
4	REW4-TP2	5	0	6	10	16	10	28	3
5	REW4-TP3	5	6	12	11	17	5	23	3
6	REW5-TP1	3	39	42	44	47	5	20	1
7	REW5-TP2	3	39	42	44	47	5	20	1
8	REW5-TP3	3	42	46	47	51	5	17	1
9	REW5-TP4	3	42	46	47	51	5	17	1
10	REW6-TP1	3	46	49	48	51	2	14	1
11	REW6-TP2	3	32	35	37	40	5	23	1
12	REW7-TP4	3	32	35	37	40	5	23	1
13	REW8-TP1	3	12	15	31	34	19	49	1
14	REW9-TP1	3	35	39	37	41	2	20	1
15	REW12-TP1	3	49	53	51	55	2	14	1
16	REW12-TP2	3	49	53	51	55	2	14	1
17	REW12-TP3	3	53	56	55	58	2	14	1
18	REW12-TP4	3	53	56	55	58	2	14	1
19	Testing (REW-BH1)	5	62	69	76	83	14	14	1
20	Testing (REW4-TP)	6	12	26	14	28	2	19	3
21	Backfill (REW4-TP)	2	26	32	28	34	2	20	**3**
22	Testing (REW5-9-TP)	6	73	83	73	83	0	0	1
23	Backfill (REW5-9-TP)	2	87	89	87	89	0	0	1
24	Testing (REW12-TP)	6	59	69	59	69	0	10	1
25	Backfill (REW12-TP)	2	73	75	77	79	4	12	1

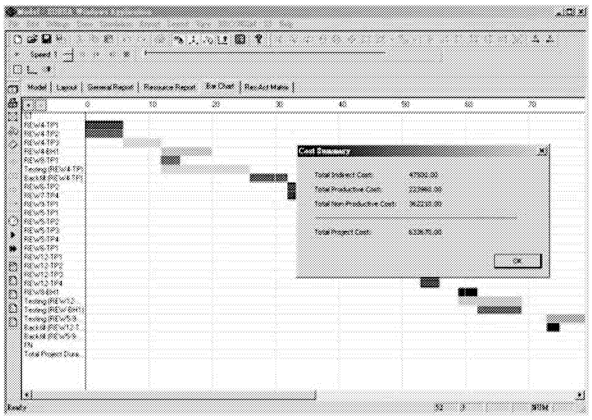
Figure 2(a) S3 Cost Budgeting

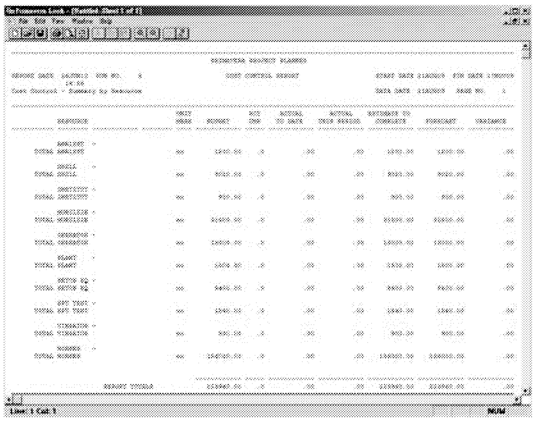
Figure 2(b) P3 Cost Budgeting

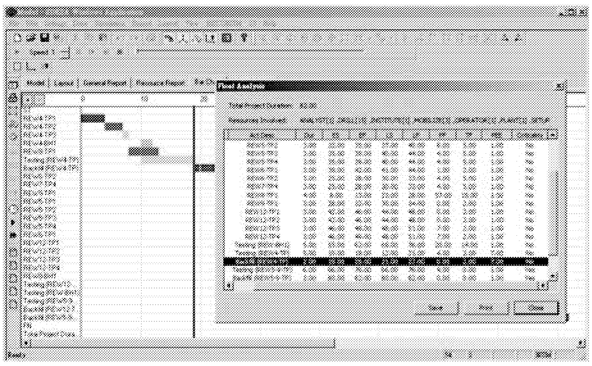

Figure 3 (a) S3 Scheduling Analysis Report

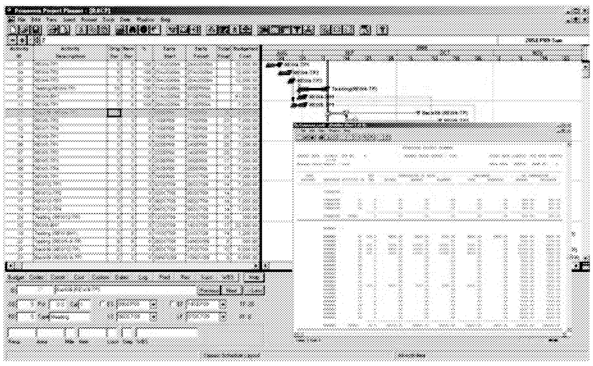

Figure 3(b) P3 Scheduling Analysis Report

Table 8 S3 Cost Analysis Report

	Planned	Update
Total Indirect Cost	$47,500	$44,000
Total Productive Cost	**$223,960**	$201,830
Total Non-Productive Cost	$362,210	$312,930
Total Project Cost	**$633,670**	$558,760

Table 9 P3 Cost Analysis Report

	Update
Actual Cumulative to Date (AC)	$62,610
Earn Cumulative to Date (EV)	$85,180
Planned Cumulative to Date (PV)	$74,610
Cost Variance	$22,570
Schedule Variance	$10,570
Budget At Completion	**$223,960**
Estimate At Completion	$201,390
Cost Performance Index (CPI)	**1.36**
Schedule Performance Index (SPI)	**1.14**
To Complete Performance Index (TCPI)	1

Table 10 EVA Analysis enable by S3 and P3

		Consumed 1 Day Total Float 50% Complete	Consumed 2 Day Total Float 75% Complete	1 Day Delay 95% Complete
P3	Actual Cumulative to Date (AC)	$65,610	$67,110	$68,010
	Earn Cumulative to Date (EV)	$88,180	$89,680	$90,580
	Planned Cumulative to Date (PV)	$85,080	$85,130	$85,180
	Cost Variance (CV)	$22,570	$22,570	$22,570
	Schedule Variance (SV)	$3,100	$4,550	$5,400
	Budget At Completion (BAC)	**$223,960**	**$223,960**	**$223,960**
	Estimate At Completion (EAC)	$204,390	$205,890	$206,790
	Cost Performance Index (CPI)	1.34	1.34	1.33
	Schedule Performance Index (SPI)	1.03	1.05	1.06
	To Complete Performance Index (TCPI)	0.98	0.97	0.96
S3	Total Indirect Cost	$44,000	$44,000	$47,500
	Productive Cost	$201,830	$207,830	$210,830
	Non Productive Cost	$312,930	$286,139	$356,080
	Total Project Cost	**$558,760**	**$537,960**	**$614,410**

CONCLUSIONS

In conclusion, findings of this research help construction managers accurately keep track of schedule and cost with the awareness of the earned value analysis limitations. By newly defined "Project Time Extension (PTE)" and "Productive and Non-Productive Cost", the project time and cost could be estimated with accuracy.

This research has proved that to increase the EVA accuracy, the following points should be noted. (1) Accurate resource- and calendar-constrained scheduling networks. (2) The accurate estimation of resource costs (including the productive cost and non-production cost). (3) The precise total float analysis and project time extension serving as additional indicators to check against the performance indices.

In addition, the P3 is incapable to produce and track constrained schedules and the activity TF value generated is misleading. Enabled by schedule simulations, the prototyped S3 is capable to generate precise constrained schedule for scheduling updating; and facilitate the schedule analysis, including accurate total float value, the project time extension and the non-productive cost.

Assisted with accurate EVM indicators, the planners can effectively monitor the time and cost performances of a highly constrained schedule, increasing the chances of successfully delivering the project.

REFERENCES

Christensen, D. S. (1993). "Determining an accurate estimate at completion", National Contract Management Journal (25), 17-25.

de la Garza, J. M. and Kim, K. (2005). "Evaluation of the Resource-Constrained Critical Path Method Algorithms", Journal of Construction Engineering and Management, 131(5), 522-532.

de la Garza, J. M. and Kim, K. (2009). "Application of the Resource-Constrained Critical Path Method to Multiple Calendars and Progressed Schedules", Proceedings of the 2009 Construction Research Congress, 339, 93.

Eldin, N. N. (1989). "Measurement of Work Progress: Quantitative Technique", Journal of Construction Engineering and Management, 115(3), 462-474.

Kim, B. C. and Reinschmidt, K. F. (2010). "Probabilistic Forecasting of Project Duration Using Kalman Filter and the Earned Value Method", Journal of Construction Engineering and Management, 136(8), 834-843.

Lukas, J. A. (2008). "Earned Value Analysis – Why it Doesn't Work", AACE International Transactions (01), 1–10.

Lu, M. (2003). "Simplified Discrete-Event Simulation Approach for Construction Simulation", Journal of Construction Engineering and Management, 129(5), 537-546.

Lu, M. and Li, H. (2003). "Resource-Activity Critical-Path Method for Construction Planning", Journal of Construction Engineering and Management, 129(4), 412-420.

Lu, M. and Lam, H. C. (2008). "Critical Path Scheduling under Resource Calendar Constraints", Journal of Construction Engineering and Management, 134(1), 25-31.

McConnell, D. R. (1985). "Earned Value Technique for Performance Measurement", Journal of Management in Engineering, 1(2), 79-94.

Project Management Institute (2005). "Practice Standard for earned value management", Project Management Institute, Inc.

Project Management Institute (2008). "A guide to the project management body of knowledge", 4th Edition, Project Management Institute, Inc.

Solomon, P. J. and Young, R. R. (2007). "Performance-based earned value", Hoboken, N.J.: John Wiley & Sons, Inc., Pub.