Understanding Schedule Progress Using Earned Value and Earned Schedule Techniques at Path-Level

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Christian Capone[1[✉] [0000-0002-8970-5802]] and Timur Narbaev[1[✉] [0000-0002-6401-2700]]

[1] Kazakh-British Technical University, Tole bi street 59, Almaty, Kazakhstan

c_capone@ise.ac
t.narbaev@kbtu.kz

Abstract. Project monitoring and control is one of the core processes of effective production planning and scheduling. As part of this process, earned value management (EVM) is used to measure and forecast the duration and cost of production projects and activities. Using the EVM-based earned schedule (ES) value, the schedule variance (SV(t)) metric is calculated. This metric is further used to analyze the schedule progress. Based on this, potential schedule delays and slack times are calculated on both project-level and path-level. However, commonly in practice, they are derived from SV(t) values on the project-level. Moreover, the research on an individual path level or comparison of SV(t) on the project-level with the ones of the path-level is limited. This study proposes such a comparative analysis. The findings reveal misleading results regarding the project-level schedule analysis outcomes due to inconsistency in the computations from both path- and project-levels. For example, when the project-level analysis suggests a schedule delay the path-level analysis shows the project has no delay. Using a hypothetical production project, this study demonstrates how and when such inconsistent outcomes may arise. This study pioneers such concepts as "false positives" and "false negatives". Based on its findings, the study discloses prospects for future research in this area.

Keywords: Production scheduling, Earned value management, Schedule network analysis, Misleading outcomes.

1 Introduction

Project monitoring and control is one of the core processes of effective production planning and scheduling. It helps to analyze the schedule progress and cost performance in ongoing projects, upon which duration or budget deviations from the original project plan can be measured [1]. Not well-defined scope, poor risk management, and ineffective monitoring and control are the main reasons why projects continue to fail [2]. The underperforming organizations in project management have a project success rate of 32%, and as a consequence, 9.9% of the project budget is wasted due to poor project performance [3]. As part of the monitoring and control process, earned value management (EVM) measures and forecasts the duration and cost outcomes of production projects and activities [4]. EVM consists of tracking the project's progress by contrasting the work's scope and actual costs to the project schedule and budget defined in the original plan [5–7].

However, some studies demonstrated that the EVM technique might lead to inconsistent results regarding the schedule progress analysis [8–10]. Inconsistency occurs when comparing the results derived from project-level analysis versus path-level analysis. This study presents and analyzes such inconsistencies and pioneers the concept of "false positive" or "false negative." For example, when the project-level analysis suggests a schedule delay, the path-level analysis shows the project has, in fact, no delay ("false positive"). Consequently, if not prevented, such inconsistency may lead to misleading estimates of duration in ongoing projects.

The purpose of this paper is to present how and when the EVM technique shows the above inconsistencies as to the schedule progress analysis. Using a hypothetical production project, the study shows that such inconsistency occurs when comparing the project-level results with ones of the individual path-level.

2 Theoretical Background

Table 1 summarizes the key concepts used in this paper. EVM schedule analysis is founded on two metrics, earned value (EV) and planned value (PV). EV is the budgeted cost of the work done and therefore earned. EV is then compared to PV, the budgeted cost of the work planned, to obtain the schedule variance (SV):

$$\mathrm{SV} = \mathrm{EV} - \mathrm{PV} \tag{1}$$

If SV is positive, then according to equation (1), the amount of work earned (EV) is exceeding the amount of work planned (PV), and therefore the project is ahead of its schedule. On the contrary, if SV is negative, the project is behind its schedule [11, 12].

It is noted that SV, as per equation (1), raises one concern. SV is not directly connected to the schedule, and indeed its dimension is in monetary units and not in time units. Furthermore, assessing the project schedule progress using this indicator leads to unreliable conclusions [13, 14].

An attempt to overcome this deficiency of SV was proposed by the Earned Schedule (ES) technique [13]. The ES metric is equal to time when the PV was supposed to be equal to EV and therefore is a better indication of the schedule progress. Then, ES can be compared with Actual Time (AT) to obtain Schedule Variance, SV(t):

$$\mathrm{SV(t)} = \mathrm{ES} - \mathrm{AT} \tag{2}$$

If SV(t) is positive, then the project is ahead of its schedule. Instead, if SV(t) is negative, the project is behind its schedule.

After our reflections, it becomes clear that equation (2) is inaccurate because ES does not consider how the tasks are distributed in relation to their predecessors and successors (project topology). The inaccuracy becomes important when the project has a predominant number of parallel activities over sequential activities [15].

This is the reason why Lipke is suggesting to use SV on critical path only when project has parallel activities (i.e. multiple paths).

Table 1. Glossary of the key concepts.

Abbreviation	Meaning
EVM	Earned Value Management
EV	Earned Value
PV	Planned Value
SV	Schedule Variance
ES	Earned Schedule
AT	Actual Time
SV(t)	Schedule Variance from Earned Schedule
CPM	Critical Path Method
FP	Fan-in Path
CP	Critical Path

Project topology can be described using the Critical Path Method (CPM), in which the project's tasks can be represented by an oriented graph (network) [16]. The longest path, named the critical path, is the one that characterizes the project in terms of its duration. Any delay of the activities on the critical path (critical activities) causes a project delay. Instead, the non-critical paths have a certain degree of slack, i.e., they can be delayed without delaying the project. The total path slack is defined as the time when the path can be delayed without delaying the project [17, 18].

3 Methodology

Equations (1) and (2) are defined and calculated at the project-level, and therefore, they cannot consider the project topology. Instead, when equations (1) and (2) are calculated at path-level, an indication of the project performance in critical activities separated from the project performance in non-critical activities is provided. Consequently, path-level calculations give more information on what is happening in the critical path and to which extent the critical path can be affected by non-critical activities.

Fig. 1 shows the tasks, their durations, and dependencies of a fictional production project with 7 activities. An example of such a production project can be an assembly line construction: the critical activities concern the installation of a conveyor belt. The project has a duration of 14 weeks. The other non critical activities are in the fan-in paths (FP). FP is the partial path constituted by non-critical activities merging into a critical path and it do not contain any critical activity. In FP1 fan-in path, we have the conveyor belt's power line installation and testing. The power line installation cannot start before week 5, should end before week 10 but requires only 3 weeks of work (therefore, have 2 weeks of slack). There is just one activity in FP2 fan-in path: the production plant's legal authorities' signatures. This activity requires 2 weeks of work, should start not earlier than week 4 and should end before week 12 (hence its slack is 5 weeks).

Fig. 1 represents in red the critical activities which resemble the critical path (CP1). FP1 is the FP represented by activities B-C. It is merging into the critical path A-E-F-G and having a slack of 2 weeks. FP2 is the FP represented by activity D, merging into the critical path A-E-F-G and having a slack of 5 weeks. In Fig. 1 it is also recorded the project baseline, including the planned budget for each activity and each week (represented by the figures in the cell). PV and cumulative Planned Values (CumPV) are calculated both at project-level (in figures, column "Level" with the value of "Project") and at path-level (in figures, column "Level" with the value of "CP1" for the critical path, "FP1" and "FP2" or the fan-in paths).

				WEEKS													
Level	Activity	Duration	Predecessors	1	2	3	4	5	6	7	8	9	10	11	12	13	14
CP1	A	4	-	20	10	5	30										
FP1	B	2	A					20	10								
FP1	C	1	B							40							
FP2	D	2	A					40	30								
CP1	E	5	A					30	30	20	20	30					
CP1	F	2	C, E										10	10			
CP1	G	3	D, F												20	30	20
Project			PV	20	10	5	30	90	70	60	20	30	10	10	20	30	20
Project			CumPV	20	30	35	65	155	225	285	305	335	345	355	375	405	425
CP1			PV	20	10	5	30	30	30	20	20	30	10	10	20	30	20
CP1			CumPV	20	30	35	65	95	125	145	165	195	205	215	235	265	285
FP1			PV	0	0	0	0	20	10	40	0	0	0	0	0	0	0
FP1			CumPV	0	0	0	0	20	30	70	70	70	70	70	70	70	70
FP2			PV	0	0	0	0	40	30	0	0	0	0	0	0	0	0
FP2			CumPV	0	0	0	0	40	70	70	70	70	70	70	70	70	70

Fig. 1. Project baseline

The authors will discuss two different possible project executions in the next section, and EVM/ES metrics will be calculated using both the classical approach (at project-level) and our proposed methodology (at path-level).

4 Results and Findings

Fig. 2 and Fig. 3 presents two different possible scenarios of the project execution. ES, EV, and SV(t) are calculated for each of the 2 scenarios, both at the path-level and at project-level. For both scenarios, the study analyzes the circumstance in which SV(t) detects a "false positive."

4.1 Scenario 1: Non-critical Fan-In Path Delayed less than its Slack

Fig. 2 shows the project- and path-level's EV, ES, and SV(t) when the critical path (activities A-E-F-G) is not delayed (and therefore, the project duration is aligned with the project baseline). There is a delay in a non-critical activity (activity D), on FP2, for an amount less than the path total slack (the slack is 5 weeks, the delay of activity D is 2 weeks).

		WEEKS													
Level	**Activity**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
CP1	A	20	10	5	30										
FP1	B					20	10								
FP1	C							40							
FP2	D					20	15	15	20						
CP1	E					30	30	20	20	30					
CP1	F										10	10			
CP1	G												20	30	20
Project	PV	20	10	5	30	90	70	60	20	30	10	10	20	30	20
Project	CumPV	20	30	35	65	155	225	285	305	335	345	355	375	405	425
Project	EV	20	30	35	65	135	190	265	305	335	345	355	375	405	425
Project	ES	1,00	2,00	3,00	4,00	4,78	5,50	6,67	8,00	9,00	10,00	11,00	12,00	13,00	14,00
Project	SV(t)	0,00	0,00	0,00	0,00	-0,22	-0,50	-0,33	0,00	0,00	0,00	0,00	0,00	0,00	0,00
CP1	PV	20	10	5	30	30	30	20	20	30	10	10	20	30	20
CP1	CumPV	20	30	35	65	95	125	145	165	195	205	215	235	265	285
CP1	EV	20	30	35	65	95	125	145	165	195	205	215	235	265	285
CP1	ES	1,00	2,00	3,00	4,00	5,00	6,00	7,00	8,00	9,00	10,00	11,00	12,00	13,00	14,00
CP1	SV(t)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
FP1	PV	0	0	0	0	20	10	40	0	0	0	0	0	0	0
FP1	CumPV	0	0	0	0	20	30	70	70	70	70	70	70	70	70
FP1	EV	0	0	0	0	20	30	70	70	70	70	70	70	70	70
FP1	ES					5,00	6,00	7,00							
FP1	SV(t)					0,00	0,00	0,00							
FP2	PV	0	0	0	0	40	30	0	0	0	0	0	0	0	0
FP2	CumPV	0	0	0	0	40	70	70	70	70	70	70	70	70	70
FP2	EV	0	0	0	0	20	35	50	70	70	70	70	70	70	70
FP2	ES					4,50	4,88	5,33	8,00						
FP2	SV(t)					-0,50	-1,13	-1,67	0,00						

Fig. 2. Scenario 1. Critical Path (CP1) is executed according to the baseline. Activity D, which belongs to FP1, is behind schedule but within its total path slack.

The project-level ES values show that the project has a delay in weeks 5, 6, and 7, with the corresponding SV(t) values being negative. However, the project-level results are misleading since they generate a "false positive." Indeed, the project is not experiencing any delay.

Contrary to this, the SV(t) values at the critical path-level capture the correct project schedule status (no delay). For the critical path CP1, SV(t) is equal to 0 from week 1 to week 14, and therefore no delay is identified. For FP1, SV(t) is also equal to 0 (no delay). For FP2, SV(t) at FP2 level shows that the delay is less than the FP2 total slack, which suggests no delay at the project-level. Hence, project managers should take no corrective measures, even though Equation (2) at the project-level suggests this.

4.2 Scenario 2: Non-critical Fan-In Path Delayed more than its Slack

Fig. 3 shows the project's EV, ES, and SV(t) when it experiences a delay in non-critical activities B and C, on FP1, for an amount that is more than the path total slack (the total path slack is 2 weeks, the delay of activities B and C is 3 weeks).

		WEEKS													
Level	Activity	1	2	3	4	5	6	7	8	9	10	11	12	13	14
CP1	A	20	10	5	30										
FP1	B					10	10	10							
FP1	C								10	10	20				
FP2	D					40	30								
CP1	E					30	30	20	20	30					
CP1	F											10	10		
CP1	G													40	30
Project	PV	20	10	5	30	90	70	60	20	30	10	10	20	30	20
Project	CumPV	20	30	35	65	155	225	285	305	335	345	355	375	405	425
Project	EV	20	30	35	65	145	215	245	275	315	335	345	355	395	425
Project	ES	1,00	2,00	3,00	4,00	4,89	5,86	6,33	6,83	8,33	9,00	10,00	11,00	12,67	14,00
Project	SV(t)	0,00	0,00	0,00	0,00	-0,11	-0,14	-0,67	-1,17	-0,67	-1,00	-1,00	-1,00	-0,33	0,00
CP1	PV	20	10	5	30	30	30	20	20	30	10	10	20	30	20
CP1	CumPV	20	30	35	65	95	125	145	165	195	205	215	235	265	285
CP1	EV	20	30	35	65	95	125	145	165	195	195	205	215	255	285
CP1	ES	1,00	2,00	3,00	4,00	5,00	6,00	7,00	8,00	9,00	9,00	10,00	11,00	12,67	14,00
CP1	SV(t)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-1,00	-1,00	-1,00	-0,33	0,00
FP1	PV	0	0	0	0	20	10	40	0	0	0	0	0	0	0
FP1	CumPV	0	0	0	0	20	30	70	70	70	70	70	70	70	70
FP1	EV	0	0	0	0	10	20	30	40	50	70	70	70	70	70
FP1	ES					4,50	5,00	6,00	6,25	6,50	7,00				
FP1	SV(t)					-0,50	-1,00	-1,00	-1,75	-2,50	-3,00				
FP2	PV	0	0	0	0	40	30	0	0	0	0	0	0	0	0
FP2	CumPV	0	0	0	0	40	70	70	70	70	70	70	70	70	70
FP2	EV	0	0	0	0	40	70	70	70	70	70	70	70	70	70
FP2	ES					5,00	6,00								
FP2	SV(t)					0,00	0,00								

Fig. 3. Case 2. Non-critical activities B and C (from FP1) are behind the schedule more than the path slack. There is an impact on the critical path (CP1).

The project-level ES values show that the project has a delay in weeks from 5 to 9, with the corresponding SV(t) values being negative. However, also in this case, the project-level results are misleading since they generate a "false positive." The project is not experiencing any delay during weeks 5-9 but only after week 10, when the cumulative delay in FP1 exceeds its slack. SV(t) values at the critical path-level capture this status: no delay during weeks 5-9, but from week 10. Therefore, project managers are suggested by SV(t) at the project-level to activate countermeasures to put in track the project from week 5, while this is needed only from week 10.

5 Conclusions

It is critical to have reliable project monitoring metrics to control the production project duration during its execution. Such metrics also help introduce timely corrective actions (i.e., when the project is not adhering to the baseline) and estimate project outcomes (i.e., if the project final duration needs to be computed). The EVM approach with its EV, PV, and ES metrics has been used in project management practice to perform such actions. Even though EVM is a widely adopted tool in practice, it has some limitations. It might lead to inconsistent results as to the schedule progress analysis.

This paper demonstrates this inconsistency when comparing the results derived from project-level analysis versus path-level analysis. In terms of duration analysis, the ES and SV(t) metrics calculated at the project-level could not discern what happens on the path-level. Using a hypothetical production project's schedule, this study introduced 2 possible execution scenarios to demonstrate these inconsistent outcomes. The metrics at the project-level gave contradictory results compared to the metrics at the path-level.

Scenario 1 was the case when the project has had a delay in its non-critical activities. Nevertheless, this delay was absorbed by the fan-in path slack. The metrics computed at the project-level detected this delay, while in fact the project was not behind its schedule ("false positive"). Scenario 2 was the case when the project had a delay in its non-critical activities. However, this delay was not totally absorbed by the fan-in path slack. The metrics computed at the project-level showed this delay by the amount of time that did not reflect the project's actual duration.

This study revealed the reason for such inconsistent outcomes. Inconsistency was originated because the project was assessed at the project-level and not at the path-level. Also, the fan-in paths were monitored closely to detect the slack usage and assess any impact on the critical path.

Therefore, to monitor the schedule progress in ongoing projects based on the actual schedule status, the authors suggest analyzing ES and SV(t) at the path-level and not only at the project-level. It is also essential to consider the slacks in fan-in paths.

Future research is suggested in this area. First, other schedule outcome scenarios should be analyzed. Second, the impact of the path-level schedule analysis on the duration estimation should be analyzed. Third, empirical analysis with multiple project data should be conducted to foresee the research and practical generalizations.

Practitioners in the industry can use the proposed approach for more realistic schedule analysis and duration management in their ongoing projects. The project schedule must be analyzed not only on the aggregated project-level, but also on the individual path-levels. Then, the results of such separate assessments should be compared. Only after this, appropriate corrective actions for more informed schedule management should be taken.

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