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ENHANCING EARNED VALUE ANALYSIS WITH INTRINSIC SCHEDULE PERFORMANCE METRICS

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ABSTRACT

The Earned Value Analysis (EVA) is a well-known, widely taught and used project monitoring method in both public and private sectors. It nonetheless has some limitations that have led to the emergence of complementary methods like the Earned Schedule (ES) or the Earned Duration Method (EDM). In this paper, another method is proposed that aims to address the limitations of EVA in terms of schedule performance assessment. This method introduces intrinsic schedule performance metrics that (1) ensure that the schedule performance of the overall project and that of individual work packages (WPs) can be measured reliably and independently from the performance of preceding WPs; and (2) do not converge to neutral values at the end of the project or WP (e.g. schedule variance converging to zero). This means that not only are project managers provided with reliable data throughout the entire project, but it also allows to record the real schedule performance of past projects for benchmarking and future planning. The proposed metrics and their application are demonstrated using simulations illustrating their benefits, or complementarity with current EVA metrics.

KEYWORDS

Earned value analysis, project, schedule, performance, monitoring.

INTRODUCTION

Earned Value Management (EVM) is one of the most long-lasting project management methods to this day. Detailed in the international standard ISO 21508:2018 (ISO, 2018), it is now well-known and used in both public and private sectors. Countries like the USA, Australia, Canada, Japan, the UK and Sweden now use the method extensively and participate in the progression of EVM in the field through the International Performance Management Council (De Marco & Narbaev, 2013).

The Earned Value Analysis is the quantitative technique used as part of EVM to evaluate project performance in terms of time and cost. One of the selling points of EVA is that it calculates metrics that measure cost and time performance independently from one another. However, some limitations of the EVA have also long been highlighted. In particular, the EVA's Schedule Performance Index (SPI) and Schedule Variance (SV) metrics are known to lose interpretative meaning once two thirds of a work package (WP) (or project) is completed (Corovic, 2006), at which point they converge to "perfect" schedule performance (i.e. SPI=1.0 and SV=0.0).

The Earned Schedule (ES) method has been developed by Walt Lipke in the USA and Kym Henderson in Australia (Lipke, 2003; APM, 2013) in order to express the schedule performance

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in units of time instead of cost (EVA expresses schedule in units of cost), and to address the convergence of the EVA SV and SPI metrics. Its simplicity and compatibility with the existing EVA technique have led to its widespread adoption and it is presented in ISO 21508:2018 (ISO, 2018). Figure 1(a) shows a typical diagram used to illustrate the EVA and ES methods and how their metrics are calculated on the graph. The formulas for calculating their corresponding performance metrics are summarised in Table 1 (Lipke, 2003; ISO, 2018).

More recently, the Earned Duration Management (EDM) method was proposed by Khamooshi and Golafshani (2014) as a third alternative that distinguishes micro and macro level performance assessment and computes performance (and forecasts) with more direct relation to schedule-related information. Further extensions to EVM and EDM have also been published recently that focus on introducing new fine-tuned metrics (e.g. (Ballesteros-Pérez et al., 2019)), introducing stochastic measures (e.g. (Zohoori et al., 2019; Hendiani et al., 2020)) and improving the forecasting methods (e.g. (Vandevoorde and Vanhoucke, 2006; André de Andrada et al., 2019)).

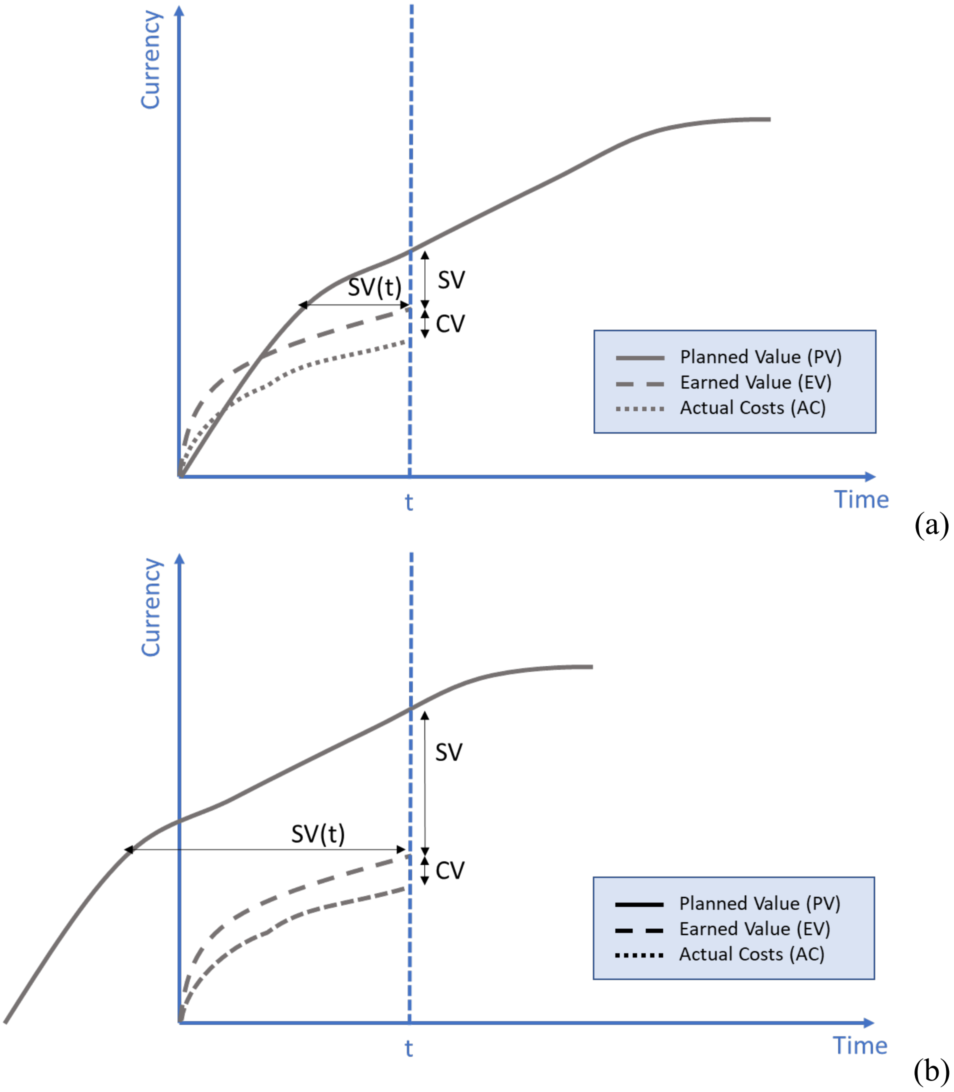


Figure 1: (a) Illustration of the EVA metrics (SV and CV) and the ES metric SV(t): (a) when the actual start date equals the planned start date; and (b) when the actual start date is delayed.

Table 1: Formulas for the calculation of the main performance metrics calculated in the EVA and ES techniques. In this table, AC is the Actual Cost and PV is the Planned Value.

Technique	Metric Name	Metric Acronym	Formula
EVA	Cost Variance	CV	CV = EV - AC
	Cost Performance Index	CPI	CPI = EV / AC
	Schedule Variance	SV	SV = EV - PV
	Schedule Performance Index	SPI	SPI = EV / PV
ES	Schedule Variance [time]	SV(t)	SV(t) = t' - t with t' the time at which PV(t') = EV(t)
	Schedule Performance Index [time]	SPI(t)	SPI(t) = t' / t

Despite the improvements provided by the ES method, some challenges remain. First of all, it must be highlighted that the EVA method does not require the cumulative PV curve to calculate any of its metrics. These are only calculated based on PV, EV and AC values at the performance measurement time t. In contrast, the calculation of EV(t) requires computing the time t' when PV(t') = EV(t). Besides, this requires the PV and EV curves to be aligned to start on the same date. If that is not the case, then SV(t) loses meaning, as shown in Figure 1(b). It is interesting to note that this requirement is rarely explicitly stated, even in the ISO standard. This is likely because project managers will typically assess schedule performance at the overall project level, at which the start dates of the EV and PV curves will naturally match. However, this is not necessarily true for the Work Packages (WPs) making up the project, due to precedence relationships which can cause the delay in one WP to generate delays in following WPs. In such situations, any following WP will show poor schedule performance from the start, even if they are delivered as planned. These observations also apply to the EDM method.

This paper attempts to provide a solution to the following research problem: can the EVA technique be refined, or extended, to give schedule performance metrics that remain meaningful throughout the delivery of a WP (and the overall project) and do not require the processing of cumulative data for their calculation?

The next section "Method" presents the proposed intrinsic Schedule Performance metrics, with full details on their calculations. The benefits of these new metrics in comparison to existing EVA metrics, and the ES method, are illustrated in the section "Demonstration" with an example, that is kept as simple as possible but perfectly highlights the weaknesses of existing EVA schedule performance metrics (and ES method) and benefits of the proposed new ones. Finally, the section "Conclusion" summarises the results obtained and discusses future works.

METHOD

INTRINSIC SCHEDULE PERFORMANCE

The comparison between Figure 1(a) and Figure 1(b) shows how the start date of a WP does not affect the cost performance metric CV (and similarly CPI). In other words, the cost performance metrics (CV and CPI) rightly capture the *intrinsic* cost performance of the WP. In contrast, the figures also show that the start date does have an impact on the schedule performance metrics SV and SPI. In fact, even if a WP is delivered as planned in terms of intrinsic schedule performance, if its start is delayed, then its schedule performance metric SV is negative (and CPI < 1.0) from the outset and for its entire duration up until its completion (due to SV systematically converging to SV = 0.0). This shows that SV and SPI, as calculated in the EVA method, do not capture the *intrinsic* schedule performance of the WP – and should thus be interpreted with great care. It is important to note that these observations also apply to the ES and EDM methods.

In order to determine the *intrinsic schedule performance* of a WP, the PV curve must be (re-)aligned with the EV curve, by setting the planned start date to be the same as the actual start date of the WP. In other words, a separate, *intrinsic* schedule performance baseline (*intPV*) needs to be created for each WP in the WBS and that is set to start on the WP's actual start date. This second baseline, illustrated in Figure 2, is in effect *intrinsic* to the WP, because not impacted by the performance of preceding WPs. Note that an intPV curve needs to be created for each WP at each level in the WBS.

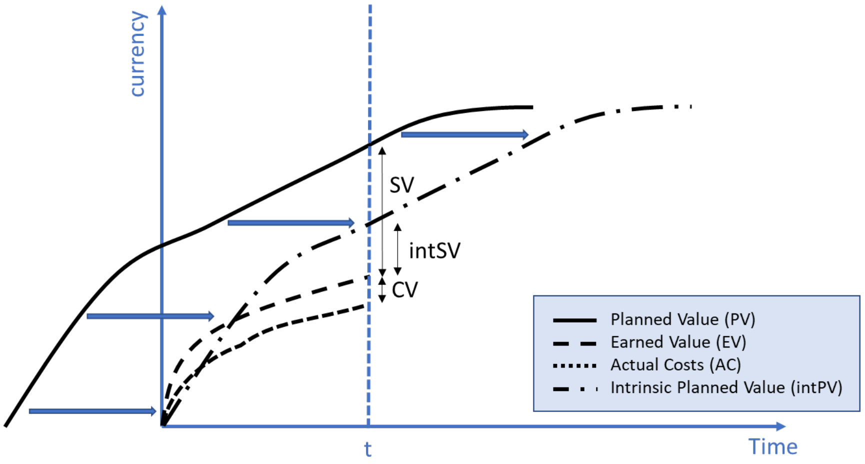


Figure 2: Illustration of the EVA and ES metrics when the intPV curve is added that is the result of (re-)aligning the PV curve with the EV curve (and AC curve).

If PV(t) is the original planned schedule performance baseline of a WP, then the intrinsic baseline intPV(t) can be obtained using the formula:

$$\begin{aligned} intPV(t) &= PV(t-d) \\ &= P\%C(t-d) \times BCWS \end{aligned}$$

where BCWS is the *Budgeted Cost of Work Scheduled*, $P\%C(t-d)$ is percentage of work complete at time (t – d), and:

$$d = S^{actual} - S^{planned}$$

is the difference between the original planned start date $S^{planned}$ and the actual state date S^{actual} of the WP (d is negative if the WP starts earlier than planned).

For completeness, we define *intP%C(t)*, the *intrinsic planned percentage complete* curve calculated as:

$$intP\%C(t) = P\%C(t-d)$$

The formula for intPV(t) then becomes:

$$intPV(t) = intP\%C(t) \times BCWS$$

intPV can now be used to calculate *intrinsic schedule performance metrics*, *intSV* and *intSPI* as:

$$\begin{aligned} intSV &= EV - intPV \\ &= (A\%C - intP\%C) \times BAC \end{aligned}$$

$$\begin{aligned} intSPI &= \frac{EV}{intPV} \\ &= \frac{A\%C}{intP\%C} \end{aligned}$$

where $A\%C$ is the *actual percentage of work complete*.

We note that the creation of an intrinsic baseline PV curve, intPV(t), may already be implemented by some practitioners, but such practice is not explicitly suggested in existing standards and most guidance documents, in relation to the ES or EDM methods.

SCHEDULE PERFORMANCE CONVERGENCE BEHAVIOUR

While intPV, as introduced above, factors out the impact of the schedule performance of preceding activities on the schedule performance of the activity of interest, intSV and intSPI still converge to 0.0 and 1.0 respectively. This behaviour is illustrated in Figure 3 with the same example where a WP takes longer to complete than planned. The bottom chart shows the evolution of the intSV value as the WP was being completed. The purple part shows the intSV conversion to 0.0, which in that case occurs once the planned duration is passed. Note that the same behaviour occurs if the WP is completed faster than planned. The only difference is that the role of the intPV and EV curves is inverted, i.e. the conversion occurs from when the WP is actually completed until its planned completion date.

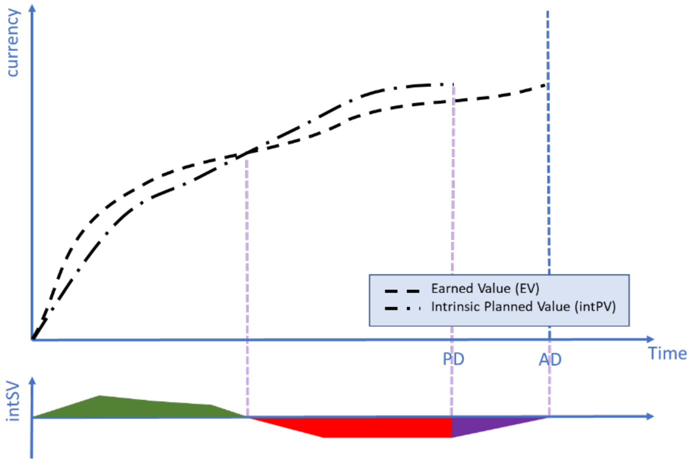


Figure 3: EVA graph for a WP concluding later than intrinsically planned. PD and AD are the planned and actual durations of the WP. The bottom plot shows the evolution of intSV.

To address this limitation, let's start with the case illustrated in Figure 3, of a WP concluding later than planned. In that case, to prevent the conversion, the intPV curve must be artificially extended. This artificial extension of the $intPV$ curve can follow various principles, depending on what may be considered the "financial impact of the difference in completion duration (e.g. delay)". Three approaches are proposed here (illustrated in Figure 4):

a) intPV continues to increase at the same average rate as planned, i.e. for t > PD:

$$intPV_{proj}(t) = \frac{BAC}{PD} \times t$$

b) intPV continues to increase at a rate that maintains intSV at the same value as it was at the time PD (in other words intSV is maintained constant from PD onwards), i.e. for t > PD:

$$intPV_{proj}(t) = EV(t) + intSV(PD)$$

c) intPV continues to increase at a rate that maintains intSPI at the same value as it was at the time PD (in other words intSPI is maintained constant from PD onwards), i.e. for t > PD:

$$intPV_{proj}(t) = EV(t)/intSPI(PD)$$

Note that these options, in particular (b) and (c), follow similar ideas as those proposed for calculating the *Independent Estimate at Completion (IEAC(t))*, i.e. forecasted duration at completion based on various metrics of past performance and assumptions for future performance, in the context of the EVA method (ISO, 2018), the ES method, or the EDM method (Corovic, 2006; Vandevoorde and Vanhoucke, 2006; Jacob and Kane, 2004).

intSV and intSPI are then calculated as normal, i.e. for t > PD:

$$intSV(t) = EV(t) - intPV_{proj}(t)$$

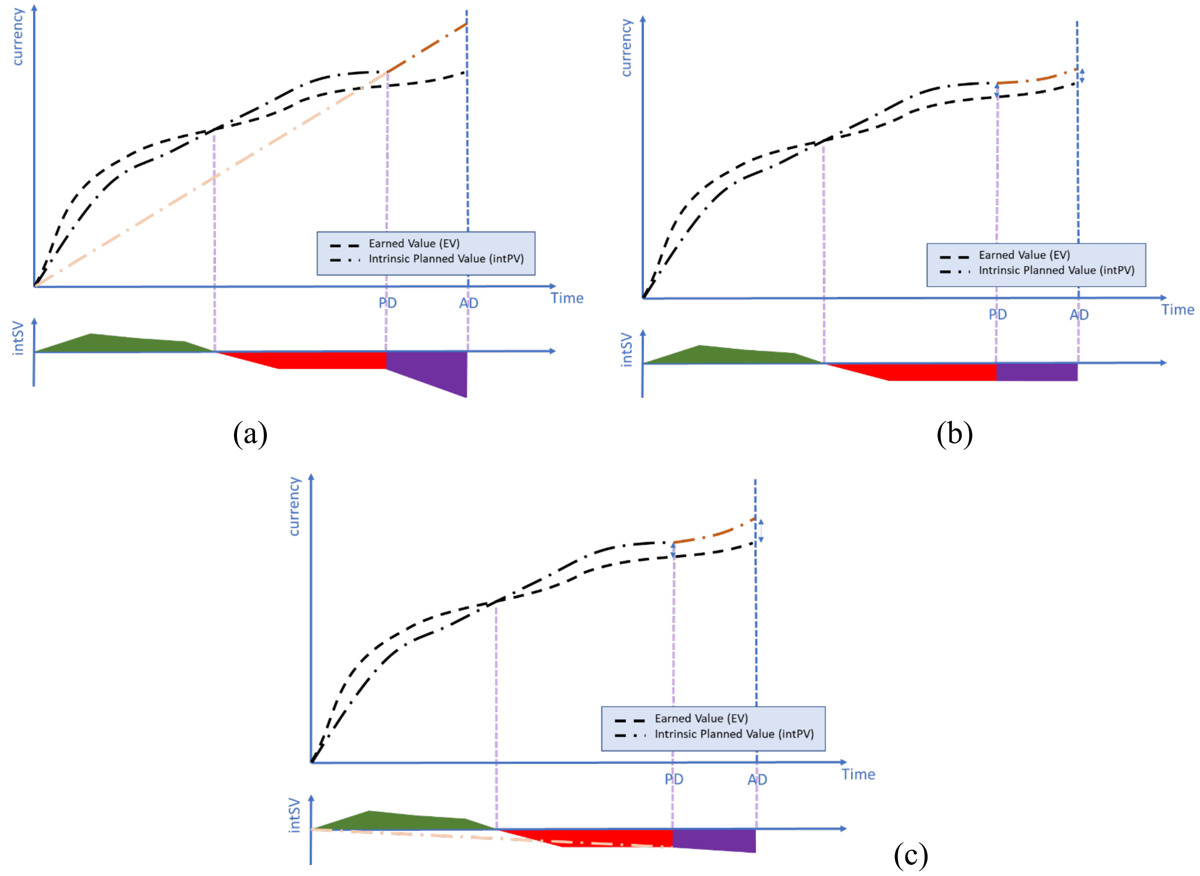
$$intSPI(t) = \frac{EV(t)}{intPV_{proj}(t)}$$

The second case is when a WP is completed earlier than planned. This is illustrated in Figure 5. To prevent the conversion in this case and maintain meaningful intSV and intSPI values, to prevent the conversion of intSV to 0.0 and intSPI to 1.0, intSV and intSPI should simply maintain their values obtained at t = AD, i.e. for t > AD:

$$intSV(t) = intSV(AD)$$

$$intSPI(t) = intSPI(AD)$$

In summary, the proposed strategy to prevent the conversion of intSV and intSPI to 0.0 and 1.0 respectively, is in effect to accrue intPV up to t = AD. In the case of a WP completing earlier than planned, accrual of intPV is simply stopped after t= AD; and in the case of a WP completing later than planned, intPV is accrued artificially after t=PD, until t= AD.



(a) (b)

(c)

Figure 4: The same EVA graph as in Figure 3, but where the intPV curve is extended from the PD to AD following three alternative strategies: (a) intPV increases at the same rate as planned; (b) intPV continues to increase at a rate that maintains intSV constant; and (c) intPV increases at a rate that maintains intSPI constant.

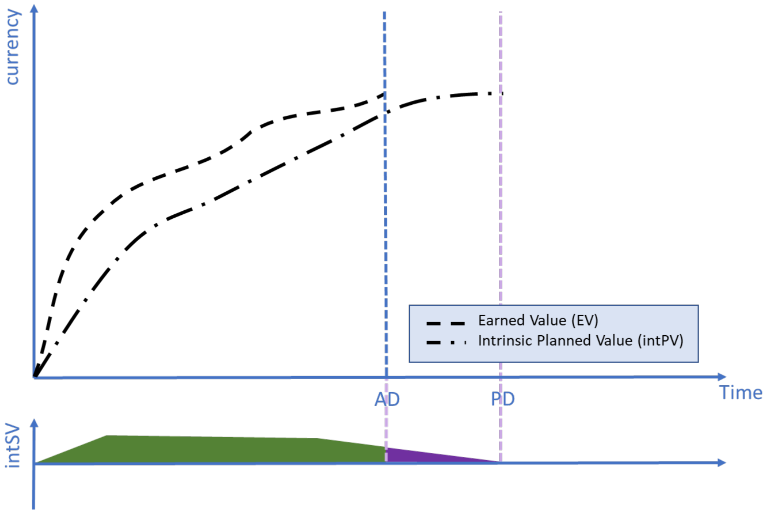


Figure 5: EVA graphs for a WP concluding earlier than planned. PD and AD are the planned and actual durations of the WP, respectively. The bottom plot shows the evolution of the intSV value as the WP was being completed.

SUMMARY

In summary, the proposed method to calculate schedule performance metrics that are intrinsic to the WP (i.e. not influenced by the schedule performance of preceding activities) and that do not converge to 0.0 (SV) and 1.0 (SPI) entails the calculation of: (1) a new curve intPV intrinsic to that WP, no matter its level in the WBS; and then (2) the proposed intrinsic schedule performance metrics intSV or intSPI.

First, the curve intPV is simply a re-baselining of the PV curve so that the planned start date equates the actual start date. Then, intSV and intSPI are calculated as follows:

$$intSV(t) = \begin{cases} EV(t) - intPV(t), & \text{if } t \leq PD \text{ and } t \leq AD \quad \text{[Case 1]} \\ EV(t) - intPV_{proj}(t), & \text{if } t > PD \text{ and } t < AD \quad \text{[Case 2]} \\ intSV(AD), & \text{if } t \leq PD \text{ and } t > AD \quad \text{[Case 3]} \end{cases}$$

$$intSPI(t) = \begin{cases} \dfrac{EV(t)}{intPV(t)}, & \text{if } t \leq PD \text{ and } t \leq AD \quad \text{[Case 1]} \\ \dfrac{EV(t)}{intPV_{proj}(t)}, & \text{if } t > PD \text{ and } t < AD \quad \text{[Case 2]} \\ intSPI(AD), & \text{if } t > AD \text{ (including for } t \leq PD) \quad \text{[Case 3]} \end{cases}$$

In the above formulas, the three cases correspond to the following contexts:

d) Case 1: WP is on-going, and its PD and AD are not reached yet.
e) Case 2: WP is on-going, and the PD has been passed (i.e. it is taking longer than planned).
f) Case 3: WP is completed but the PD has not been passed yet (i.e. it took less time than planned).

For Case 2, $intPV_{proj}$ can be calculated using either of the three formulas below depending on the expected schedule performance from the measurement point to completion (other formulas may also be considered):

$$intPV_{proj}(t) = \begin{cases} \dfrac{BAC}{PD} \times t, & \text{if projection is based on planned performance} \\ EV(t) + intSV(PD), & \text{if projection maintains } intSV \text{ measured at time } PD \\ EV(t)\ /\ intSPI(PD), & \text{if projection maintains } intSPI \text{ measured at time } PD \end{cases}$$

It must be highlighted that the method can be applied for any WP in the WBS, which includes the project overall as well.

DEMONSTRATION

To illustrate the method, Figure 6 shows a simple sequence of two WPs (1.a and 1.b) that are part of a WP higher in the WBS (1). In this diagram, the green bars represent the WPs according to the planned schedule, and the red bars represent the WPs according to the actual schedule. The green bars with the hash represent the WPs according to the intrinsic planned schedule, i.e. planned schedule baseline shifted so that the planned start date is aligned with the actual start date and (artificially) extended up until AD, if needed. We assume that the start of the overall WP was delayed due to some preceding WP having been completed late.

The intrinsic schedule performance metrics and current EVA schedule performance metrics for the two WPs and the overall WP at the end of days 2, 4, 6 and 8 are summarised in Table 2. For simplicity, but without loss of generality, all schedule performance metrics are calculated with the assumption that the PV, intPV and EV progress linearly through the WP durations. In this example, intPV is projected beyond PD using the second projection option defined above, i.e. by assuming that the intSV will remain constant until completion.

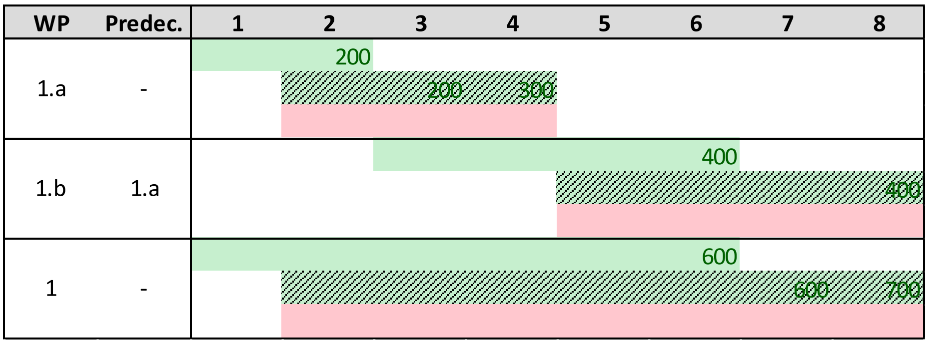


Figure 6: Gantt chart of two sequential WPs. In green: planned delivery. In red: actual delivery. In green with hash: intrinsic planned (i.e. planned baseline aligned to actual start). The numbers indicate the costs (planned and actual) of each WP.

Table 2: The intrinsic schedule performance KPIs and current EVA schedule performance KPI for the two WPs and the overall WP at the end of days 2, 4, 6 and 8.

Day	WP	intSV	intSPI	SV	SPI	intPV	PV	EV
2	1.a	-33	0.67	-133	0.33	100	200	67
	1.b	0	n/a	0	n/a	0	0	0
	1	-33	0.67	-133	0.33	100	200	67
4	1.a	-100	0.67	0	1.00	300	200	200
	1.b	0	n/a	-200	0.00	0	200	0
	1	-100	0.67	-200	0.50	300	400	200
6	1.a	-100	0.67	0	1.00	300	200	200
	1.b	0	1.00	-200	0.50	200	400	200
	1	-100	0.80	-200	0.67	500	600	400
8	1.a	-100	0.67	0	1.00	300	200	200
	1.b	0	1.00	0	1.00	400	400	400
	1	-100	0.86	0	1.00	700	600	600

The intrinsic performance metrics correctly reflect the fact that WP 1.a took 50% more time than planned and that, schedule-wise, WP 1.b is intrinsically performing as planned. In contrast, the SPI and SV values as defined in the EVA technique suggest a completely different picture with 1.a overestimating the delay at day 2 and then converging to 1.0 at day 4 when the activity is actually completed. Similarly, for WP 1.b, SV reports that the activity is behind schedule, but this is only due to the delay of WP 1.a, and not intrinsically due to WP 1.b itself. Then, at day 4, SV and SPI continue to suggest the activity is behind schedule, while it is in fact intrinsically proceeding as planned. And, again, at day 8 the SV and SPI converge to 1.0, thereby losing interpretation meaning. Looking at the overall WP 1, the SPI values suggest at day 2 that the WP is significantly behind schedule (0.33) and then delays are recovered throughout the completion of the WP until the SPI value converges to 1.0 at the end. But, in reality, WP1 does get behind schedule at the beginning due to WP 1.a, but later maintains performance with WP 1.b. This is rightly captured by intSPI that gives a 0.67 value up to day 4, and then 0.8 and 0.86 at days 6 and 8 respectively. The final value is logical since it ultimately took 7 days to deliver the WP which was initially planned for 6 days (6 / 7 = 0.86).

Because the proposed intrinsic schedule performance metrics do not systematically converge to 0.0 (SV) or 1.0 (SPI), they retain intrinsic performance which enables project management teams to more easily trace back the origins of performance deviations. These would also be very useful for organisations to store historical records of the schedule performance of common types of works, which could then be used for benchmarking and enhance the quality of planning for future projects.

In addition, as indicated earlier, because WP 1 starts later than planned, the ES metric SV(t), if calculated with the PV curve as opposed to the intPV curve, is negative from Day 1 and increases subsequently. While it would correctly capture the delay of WP 1 in the context of the broader project (SV(t) = - 2 days at t=8), this would not correspond to the intrinsic schedule performance of the WP that has a delay of only 1 day.

CONCLUSION

In this paper a new set of schedule performance metrics are proposed to complement and strengthen the existing EVA technique. The benefits of the method are that:

- It captures the intrinsic schedule performance of any WP at any level of the project WBS (including the overall project) independently from the performance of preceding activities.
- It ensures that intSPI does not systematically converge to 1, and similarly intSV does not systematically converge to 0. Instead, both continuously and correctly measure the intrinsic schedule performance throughout the duration of WP. This property is useful (1) for project management teams to be able to trace back the source of any performance deviation; and (2) for organisations to keep historical records of past schedule performance to support the planning and monitoring for future projects (e.g. a certain type of work might be more likely to cause delays).
- It does not require any additional input from that needed for the traditional EVA. It can thus easily be added to existing software solutions.
- It provides schedule performance metrics without needing to conduct any look up in the PV curve, as needed by the ES and EDM methods. But, in contrast to those methods, it reports schedule performance in units of cost as opposed to units of time. With regard to the ES and EDM methods, this paper also shows how, although never explicitly discussed in the literature, they should be applied with the intPV curve, not the PV curve.

While the experimental results positively illustrate these benefits, further validation will naturally be pursued with more complex data – ideally from real projects – in order to identify potential challenges or barriers to implementation in practice. Besides, more formal and detailed comparisons of the proposed approach with the ES and EDM methods should be conducted.

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