Schedule Adherence and Rework

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Abstract

- Rework has a negative impact on the likelihood of project success
- A significant portion of rework is caused by deviating from the project plan and its associated schedule
- The concept of schedule adherence provides an approach to increase project control and minimize the cost impact of rework
Overview

- Background
- Schedule Adherence
- Derivation of Rework
- Computation Methods
- Notional & Real Examples
- Summary
- Final Remarks
Background

- Schedule Adherence first recognized in 2004
- Desire since to understand its implications – i.e., the cost of rework
- Earned Schedule facilitates identifying constraints or impediments (C & I) and potential rework
- Minimizing C & I reduces workarounds and rework, maximizing performance
Background

- Several causes of rework other than imperfect schedule adherence
  - Poor planning
  - Defective work
  - Poor requirements management
  - Schedule compression
  - Over zealous quality assurance

- Presentation is focused to rework from imperfect schedule adherence – only
Background

- Possibly this discussion reminds those with background in quality and process improvement of the idea of “process discipline”
- ES provides the mechanism to identify and measure process performance discipline and forecast the waste – the cost of rework
Schedule Adherence

ES line positioned where PV = EV

Green areas indicate work completed
Schedule Adherence

Calculate by task: $EV_j(\text{AT}) - PV_j(\text{ES})$

- negative $\Rightarrow$ constraint or impediment
- positive $\Rightarrow$ potential waste of rework
Schedule Adherence

Measure of Schedule Adherence
P-Factor or P
\[ P = \frac{\sum EV_k}{\sum PV_k} \]

Subscript k identifies scheduled tasks
\( EV_k \) limited by \( PV_k \)
Schedule Adherence

- Characteristics of P-Factor
  - Cannot exceed 1.0
  - Equals 1.0 at project completion
  - \( P = 0.0 \) \( \Rightarrow \) performance not conforming to schedule
  - \( P = 1.0 \) \( \Rightarrow \) perfect conformance
  - \( P < 1.0 \) \( \Rightarrow \) rework likely
  - \( P \approx 1.0 \) \( \Rightarrow \) schedule is followed, milestones and interim products accomplished in proper sequence
Schedule Adherence

With the P-Factor, the PM has an indicator derived from ES which further enhances the description of project performance portrayed by EVM alone.
Derivation of Rework

- Fundamental relationships:
  - EV accrued = $\sum EV_j \times AT = \sum PV_k \times ES$
  - EV earned in concordance with the schedule:
    - $EV(p) = \sum EV_k \times AT = P \times EV$
    - ...where $EV_k \leq PV_k$ and $P = \sum EV_k / \sum PV_k$
  - EV earned not in agreement with the schedule:
    - $EV(r) = EV - EV(p) = (1 - P) \times EV$

- From earlier discussion, we know a portion of $EV(r)$ is unusable and requires rework
Derivation of Rework

Rework fraction: \( f(r) = \frac{EV(-r)}{EV(r)} \)

Usable fraction: \( f(p) = \frac{EV(+r)}{EV(r)} \)

where \( EV(r) = EV(-r) + EV(+r) \)

and \( f(r) + f(p) = 1 \)
Derivation of Rework

- Using the definitions we can describe rework, R, in terms of EV, P, and f(r):
  \[ R = EV(-r) = f(r) \cdot (1 - P) \cdot EV \]

- P and EV are obtainable from status data
- Project team’s ability to interpret requirements increases with work accomplishment

- Conditions for f(r):
  - \[ f(r) = 1 \quad \text{at} \quad C = 0 \quad \text{and} \quad f(r) = 0 \quad \text{at} \quad C = 1 \]
  - Rework fraction decreases as EV increases
  - Rate of f(r) decrease becomes larger as EV \( \Rightarrow 1 \)
Derivation of Rework

- Proposed equation for \( f(r) \) which meets conditions:
  \[
  f(r) = 1 - C^n \cdot e^{-m \cdot (1 - C)}
  \]
  where
  - \( C \) = fraction complete (EV/BAC)
  - \( e \) = natural number (2.718…)
  - \( ^{\wedge} \) = signifies exponent follows

- Exponents \( m \) and \( n \) are used to shape the \( f(r) \) curve. Values presently used: \( m = 0.5 \), \( n = 1.0 \)

- Using the values the general equation for \( R \) is:
  \[
  R = (1 - C \cdot e^{(-0.5 \cdot (1 - C)))} \cdot (1 - P) \cdot EV
  \]
Computation Methods

- The value computed for R represents the cost of rework forecast for the remainder of the project due to the present value of P.
- Although of some interest, P is not particularly useful for PMs.
- Regardless of effort invested to improve, P increases as project progresses and concludes at 1.0 at completion.
- Thus, R does not yield trend information, nor can it lead to a forecast of total cost of rework.
Computation Methods

- R can be transformed to a useful indicator by dividing by the work remaining (BAC – EV):
  \[ SAI = \frac{R}{BAC - EV} \]
  where \( SAI \) = Schedule Adherence Index

- \( SAI \) is useful for detecting trends …thus a management tool for gauging actions taken
  - \( SAI \) increasing with \( EV \) \( \Rightarrow \) SA worsening
  - \( SAI \) decreasing with \( EV \) \( \Rightarrow \) SA improving
Computation Methods

- Having SAI facilitates the calculation of rework within a performance period.

![Diagram with SAI values](image)

The units of the area is fraction complete times cost of rework per unit of budget.

Thus, rework cost is computed by multiplying the area by BAC.
To obtain the rework cost for periods \( n \) other than 1 and \( N \):

\[
R_p(n) = BAC \cdot \left[ \frac{1}{2} \cdot (SAI_n + SAI_{n-1}) \cdot (C_n - C_{n-1}) \right]
\]

For \( n = 1 \): \( R_p(1) = BAC \cdot SAI_1 \cdot C_1 \)

For \( n = N \): \( R_p(N) = BAC \cdot SAI_{N-1} \cdot (1 - C_{N-1}) \)

The cumulative accrual is the sum of the periodic values:

\[
R_{\text{cum}} = \sum R_p(n)
\]

The formula for total rework forecast is:

\[
R_{\text{tot}} = R_{\text{cum}} + SAI \cdot (BAC - EV)
\]
Computation Methods

- To clarify what $R_{tot}$ represents, it is the forecast of actual cost for rework from imperfect execution of the schedule.
- From experience, rework cost is closely aligned with planned cost.
- Generally, rework does not experience the execution inefficiencies incurred in the initial performance of the tasks.
Notional Data Example

<table>
<thead>
<tr>
<th>Status Point</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>EV</td>
<td>$14</td>
<td>$37</td>
<td>$58</td>
<td>$82</td>
<td>$97</td>
<td>$113</td>
</tr>
<tr>
<td>P</td>
<td>0.082</td>
<td>0.208</td>
<td>0.247</td>
<td>0.337</td>
<td>0.371</td>
<td>0.431</td>
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<table>
<thead>
<tr>
<th>Status Point</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
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<tbody>
<tr>
<td>EV</td>
<td>$125</td>
<td>$137</td>
<td>$157</td>
<td>$177</td>
<td>$185</td>
</tr>
<tr>
<td>P</td>
<td>0.520</td>
<td>0.650</td>
<td>0.822</td>
<td>0.955</td>
<td>1.000</td>
</tr>
</tbody>
</table>

- P values are very poor and do not exceed 0.8 until nearly 85% complete ...normally P is greater than 0.8 by 20% complete
- Because P is poor we should expect rework to be large with respect to BAC
## Notional Data Example

<table>
<thead>
<tr>
<th>Status Point</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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</thead>
<tbody>
<tr>
<td>Percent Complete</td>
<td>7.6%</td>
<td>20.0%</td>
<td>31.4%</td>
<td>44.3%</td>
<td>52.4%</td>
<td>61.1%</td>
</tr>
<tr>
<td>SA Index</td>
<td>0.072</td>
<td>0.171</td>
<td>0.267</td>
<td>0.351</td>
<td>0.407</td>
<td>0.444</td>
</tr>
<tr>
<td>Rework Forecast</td>
<td>$13</td>
<td>$29</td>
<td>$42</td>
<td>$52</td>
<td>$57</td>
<td>$60</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Status Point</th>
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<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent Complete</td>
<td>67.6%</td>
<td>74.1%</td>
<td>84.9%</td>
<td>95.7%</td>
<td>100.0%</td>
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<tr>
<td>SA Index</td>
<td>0.425</td>
<td>0.350</td>
<td>0.213</td>
<td>0.064</td>
<td>#N/A</td>
</tr>
<tr>
<td>Rework Forecast</td>
<td>$59</td>
<td>$55</td>
<td>$50</td>
<td>$47</td>
<td>$47</td>
</tr>
</tbody>
</table>

- SAI increases until ~60% complete and then improves as the project moves to completion.
- Rework forecast rapidly increases until ~30% complete, then at a slower rate peaks at $60 when 61% is reached …from there forecast decreases slightly to finish at $47 or about 25% of BAC ($185)
Notional Data Example

- SAI improves greatly after its peak value, but rework forecast improves only marginally
- Why? – there is less work remaining
Real Data Example

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>EV</td>
<td>$549,707</td>
<td>$668,776</td>
<td>$784,508</td>
<td>$881,288</td>
<td>$986,529</td>
</tr>
<tr>
<td>P</td>
<td>0.930</td>
<td>0.915</td>
<td>0.963</td>
<td>0.962</td>
<td>0.939</td>
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<th>10</th>
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</thead>
<tbody>
<tr>
<td>EV</td>
<td>$1,299,880</td>
<td>$1,422,033</td>
<td>$1,526,842</td>
<td>$1,617,976</td>
<td>$1,716,130</td>
</tr>
<tr>
<td>P</td>
<td>0.957</td>
<td>0.975</td>
<td>0.970</td>
<td>0.975</td>
<td>0.984</td>
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</thead>
<tbody>
<tr>
<td>EV</td>
<td>$1,826,991</td>
<td>$1,930,651</td>
<td>$2,015,852</td>
<td>$2,088,967</td>
</tr>
<tr>
<td>P</td>
<td>0.994</td>
<td>0.995</td>
<td>0.996</td>
<td>0.993</td>
</tr>
</tbody>
</table>

- P-Factor is high initially and increases to 0.995 by 75% complete
- CPI = 1.05 & SPI(t) = 0.98 – both are comparatively high
- Synergy between high values of P and high index values
Real Data Example

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Percent Complete</td>
<td>22.1%</td>
<td>26.9%</td>
<td>31.5%</td>
<td>35.4%</td>
<td>39.6%</td>
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<tr>
<td>SA Index</td>
<td>0.017</td>
<td>0.026</td>
<td>0.013</td>
<td>0.015</td>
<td>0.028</td>
</tr>
<tr>
<td>Rework Forecast</td>
<td>$42,138</td>
<td>$58,352</td>
<td>$36,599</td>
<td>$40,232</td>
<td>$60,325</td>
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</table>

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<tr>
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</thead>
<tbody>
<tr>
<td>Percent Complete</td>
<td>52.2%</td>
<td>57.2%</td>
<td>61.4%</td>
<td>65.0%</td>
<td>69.0%</td>
</tr>
<tr>
<td>SA Index</td>
<td>0.027</td>
<td>0.018</td>
<td>0.023</td>
<td>0.021</td>
<td>0.014</td>
</tr>
<tr>
<td>Rework Forecast</td>
<td>$59,056</td>
<td>$48,173</td>
<td>$53,875</td>
<td>$51,466</td>
<td>$46,098</td>
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</thead>
<tbody>
<tr>
<td>Percent Complete</td>
<td>73.4%</td>
<td>77.6%</td>
<td>81.0%</td>
<td>84.0%</td>
<td></td>
</tr>
<tr>
<td>SA Index</td>
<td>0.006</td>
<td>0.005</td>
<td>0.005</td>
<td>0.008</td>
<td></td>
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<tr>
<td>Rework Forecast</td>
<td>$40,004</td>
<td>$39,476</td>
<td>$39,408</td>
<td>$41,032</td>
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</tbody>
</table>

- With P values very high, SAI values are extremely low, as expected
Real Data Example

- Other observations
  - SAI highest value = 0.028, lowest = 0.005
  - SAI values for real data as much as 89 times lower than for notional data
  - Average forecast value of rework = $47K or 1.9% of BAC ($2.5M)
  - Standard deviation of forecast values = $8300, thus high bound = $47K + 3 \cdot $8.3K \approx $72K
Real Data Example

- SAI & rework plots have negative trends showing improvement after 40% complete
- Assuming trend continues, rework will conclude at less than $40K, 1.6% of BAC
Summary

- From the introduction of schedule adherence there has been a desire for the ability to forecast the cost of rework.
- The forecast capability was long thought to be too complex for practical application.
- The presentation has shown calculations are not that encumbering.
- SAI was introduced and shown to be integral to computing the forecast rework.
Summary

- The application of SAI and rework forecasting was discussed for notional and real data.
- SAI is proposed to be a viable PM tool for control of project performance, thereby enhancing the probability of a successful project.
- Including SAI and $R_{tot}$ at status reviews can be expected to heighten senior level attention to rework and process.
Final Remarks

- To encourage the application and uptake of the SAI and rework forecasting method a tool for trialing is available at the calculators page of the Earned Schedule website:

  **SA Index & Rework Calculator**
References

- “Schedule Adherence: a useful measure for project management,” *CrossTalk*, April 2008: 14-18
- “Schedule Adherence and Rework,” *CrossTalk*, TBD
- Earned Schedule Website: www.earnedschedule.com