EVA (C/SCSC) and Basics of Project Control

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Topics

- Monitoring cont’d
  - EVA (C/SCSC) Definitions and examples
  - Forecasting
- Project Control
  - General
  - Performance-adjustments
  - Target Adjustments
  - Problem diagnosis
Recall: Earned Value Approach
(Cost/Schedule Control Systems Criteria) Definitions

Integrating cost, schedule, and work performed by ascribing monetary values to each.

**Budgeted Cost of Work Scheduled (BCWS, $)** (“Earned value of work accomplished”) the value of work scheduled to be accomplished in a given period of time.

- **Actual Cost of Work Performed (ACWP, $)**: the costs actually incurred in accomplishing the work performed within the control time.
- **Budgeted Cost of Work Performed (BCWP, $)**: the monetary value of the work actually performed within the control time (= Earned Value).
- **Actual Time of Work Performed (ATWP, time)**
- **Schedule Time of Work Performed (STWP, time)**
Cost Variance

- Is project spending more or less money than anticipated for the work that I did?

- Cost Variance (CV = BCWP - ACWP)
  - + (Underrun); - (Overrun); 0 (On Budget)

- Cost Index (CI = BCWP/ACWP)
  - > 1 (Underrun); < 1 (Overrun); 1 (On Budget)
Schedule Variance

- One metric for judging if project making is “progressing” faster or slower than expected
  - More precisely: “How does the value of the work I have actually performed compare to the work I anticipated performing during this time?”
  - “Progress” here is measured in value of the work ($)
- Calculated in $ -- but here this is a proxy for value
- Schedule Variance \( (SV = BCWP - BCWS) \)
  - + (Ahead); - (Behind); 0 (On Schedule)
  - Even if just slightly ahead/behind in time, may be large if working on very expensive component of project
- Schedule Index \( (SI = BCWP/BCWS) \)
  - > 1 (Ahead); < 1 (Behind); 1 (On Schedule)
Is project spending more or less time than anticipated for the work that I did?

Measured in units of time

May be very close even if big difference in the resource spending

Time Variance  \( (TV = STWP - ATWP) \)

- + (Ahead); - (Delay); 0 (On Schedule)

Time Index  \( (TI = STWP / ATWP) \)

- > 1 (Ahead); < 1 (Delay); 1 (On Schedule)
Resource Flow Variance

- *Compares* how much expecting to *spend* during this timeframe with what actually spent – regardless of how much work got done.
- **Warning:** Doesn’t indicate bad or good. e.g. = if
  - Going faster but more cheaply than expected
  - Going slower but more expensively than expected
- **Resource Flow Variance** *(RV = BCWS - ACWP)*
  - + (Underrun); - (Overrun); 0 (On Target)
- **Resource Flow Index** *(RI = BCWS / ACWP)*
  - > 1 (Underrun); < 1 (Overrun); 1 (On Target)
Example: Gantt Chart Schedule

ACTIVITY

A  B  C  D  E  F  G

WEEKS

0  5  10  15  20  25

Non Critical Path Activity

Critical Path Activity
Example: Traditional Reporting

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>A</th>
<th>B</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>DURATION (WEEKS)</td>
<td>5</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>COST (IN $)</td>
<td>1,500</td>
<td>3,000</td>
<td>5,700</td>
</tr>
<tr>
<td>COST PER WEEK (IN $)</td>
<td>300</td>
<td>1,000</td>
<td>814</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>WEEK 1</th>
<th>WEEK 2</th>
<th>WEEK 3</th>
<th>WEEK 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ACTIVITY STATUS</td>
<td>ACTUAL COST</td>
<td>ACTIVITY STATUS</td>
<td>ACTUAL COST</td>
</tr>
<tr>
<td>A</td>
<td>STARTED</td>
<td>$500</td>
<td>IN PROCESS</td>
<td>$1,000</td>
</tr>
<tr>
<td>B</td>
<td>STARTED</td>
<td>1,000</td>
<td>IN PROCESS</td>
<td>2,000</td>
</tr>
<tr>
<td>E</td>
<td>STARTED</td>
<td>814</td>
<td>IN PROCESS</td>
<td>1,500</td>
</tr>
</tbody>
</table>
## Example: Earned Value Reporting

### SUMMARY REPORT FOR WEEKS 1 - 4

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>A</th>
<th>B</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACTUAL COST (IN $)</td>
<td>1,500</td>
<td>3,000</td>
<td>2,900</td>
</tr>
<tr>
<td>BUDGETED COST (IN $)</td>
<td>300 × 4 = 1,200</td>
<td>3,000</td>
<td>814 × 4 = 3,256</td>
</tr>
<tr>
<td>WORK PERFORMED AS % OF WORK CONTENT</td>
<td>100</td>
<td>100</td>
<td>(\frac{2}{7} = 28.6)</td>
</tr>
</tbody>
</table>
Example: Activity Analysis

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>BCWP</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$ 1,500</td>
</tr>
<tr>
<td>B</td>
<td>$ 3,000</td>
</tr>
<tr>
<td>E</td>
<td>$ 1,628</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>ACWP</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$ 1,500</td>
</tr>
<tr>
<td>B</td>
<td>$ 3,000</td>
</tr>
<tr>
<td>E</td>
<td>$ 2,900</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>BCWS</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>300 × 4 = $ 1,200</td>
</tr>
<tr>
<td>B</td>
<td>$ 3,000</td>
</tr>
<tr>
<td>E</td>
<td>814 × 4 = 3,256</td>
</tr>
</tbody>
</table>
### Example: Variances

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>BCWP - ACWP = CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$1,500 - $1,500 = $0</td>
</tr>
<tr>
<td>B</td>
<td>$3,000 - $3,000 = $0</td>
</tr>
<tr>
<td>E</td>
<td>$1,628 - $2,900 = -$1,272</td>
</tr>
</tbody>
</table>

**CUMULATIVE VARIANCE = -$1,272**

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>BCWP - BCWS = SV</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$1,500 - $1,200 = $300</td>
</tr>
<tr>
<td>B</td>
<td>$3,000 - $3,000 = $0</td>
</tr>
<tr>
<td>E</td>
<td>$1,628 - $3,256 = -$1,628</td>
</tr>
</tbody>
</table>

**CUMULATIVE VARIANCE = -$1,328**
## Variances II

\[
\begin{align*}
\text{ACTIVITY} & \quad \text{STWP - ATWP = TV} \\
A & \quad 5 - 4 = 1 \\
B & \quad 3 - 4 = -1 \\
E & \quad 2 - 4 = -2 \\
\text{Cumulative Variance} & = -2
\end{align*}
\]
## Example: Activity Indexes

<table>
<thead>
<tr>
<th>Activity</th>
<th>BCWP/BCWS</th>
<th>= SI</th>
<th>BCWP/ACWP</th>
<th>= CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1.500/1,200</td>
<td>= 1.25</td>
<td>1,500/1,500</td>
<td>= 1</td>
</tr>
<tr>
<td>B</td>
<td>3,000/3,000</td>
<td>= 1</td>
<td>3,000/3,000</td>
<td>= 1</td>
</tr>
<tr>
<td>E</td>
<td>1,628/3,256</td>
<td>= 0.5</td>
<td>1,628/2,900</td>
<td>= 0.56</td>
</tr>
</tbody>
</table>
Example: Project Indexes

The **Aggregate** Cost Index is:

\[
SI = \frac{1,500 + 3,000 + 1,628}{1,200 + 3,000 + 3,256} = 0.82
\]

\[
CI = \frac{1,500 + 3,000 + 1,628}{1,500 + 3,000 + 2,900} = 0.83
\]
## Values (in Dollars) of BCWS, BCWP, and ACWP for Weeks 1-4

<table>
<thead>
<tr>
<th>Activity</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BCWS</td>
<td>BCWP</td>
<td>ACWP</td>
<td>BCWS</td>
</tr>
<tr>
<td>A</td>
<td>300</td>
<td>500</td>
<td>500</td>
<td>300</td>
</tr>
<tr>
<td>B</td>
<td>1,000</td>
<td>1,000</td>
<td>1,000</td>
<td>1,000</td>
</tr>
<tr>
<td>E</td>
<td>814</td>
<td>300</td>
<td>814</td>
<td>814</td>
</tr>
<tr>
<td></td>
<td>2,114</td>
<td>1,800</td>
<td>2,314</td>
<td>2,114</td>
</tr>
</tbody>
</table>
# Example: Earned Value Analysis

Values of SI and CI for Weeks 1-4

<table>
<thead>
<tr>
<th>Week</th>
<th>BCWS ($)</th>
<th>BCWP ($)</th>
<th>ACWP ($)</th>
<th>CI = ( \frac{BCWP}{ACWP} )</th>
<th>SI = ( \frac{BCWP}{BCWS} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2,114</td>
<td>1,800</td>
<td>2,314</td>
<td>0.78</td>
<td>0.85</td>
</tr>
<tr>
<td>2</td>
<td>4,228</td>
<td>3,700</td>
<td>4,500</td>
<td>0.82</td>
<td>0.88</td>
</tr>
<tr>
<td>3</td>
<td>6,342</td>
<td>5,000</td>
<td>6,300</td>
<td>0.79</td>
<td>0.79</td>
</tr>
<tr>
<td>4</td>
<td>7,456</td>
<td>6,128</td>
<td>7,400</td>
<td>0.83</td>
<td>0.82</td>
</tr>
</tbody>
</table>
Example: Schedule and Cost Index

Schedule Index for the Project

Week

Cost Index for the Project

Week
Example: Integrating CI and SI

Integrating CI and SI

- Schedule problems
- Budget OK
- Schedule and budget problems
- Project on schedule and on budget
- Budget problems
- Schedule OK

SCHEDULE INDEX

COST INDEX

Week 1 (0.85, 0.78)
Week 2 (0.88, 0.82)
Week 3 (0.79, 0.79)
Week 4 (0.82, 0.83)
Topics

- Monitoring cont’d
  - EVA (C/SCSC) Definitions and examples
  - Forecasting

- Project Control
  - General
  - Performance-adjustments
  - Target Adjustments
  - Problem diagnosis
Forecasting Performance

- Critical in the performance analysis process, since it can be used to identify future performance variances and design the project control process in advance of facing real performance problems.

- Attempts to predict the conditions at a later time or the end of the project.

- Typically made repeatedly on a regular basis throughout a project.
Forecasting Completion Dates

Forecasted completion date
= Current date + (Work remaining / Expected work rate)

Expected work rate
= Expected productivity* Workers

Expected productivity
= [Work accomplished / Workers] / Time spent
Forecasting Total Costs

Forecasted total cost
= Cost spent + (Work remaining * Expected unit cost)

Expected unit cost
= Costs spent / Work accomplished
Cost Updating

- **Budget at Completion**
  - BAC = Sum BCWS on lower-level OBS
  - BAC = Sum BCWS on lower-level WBS

- **Work Remaining**
  - WR = BAC – BCWP

- **Estimate to Complete**
  - ETC = Update cost for Work remaining

- **Estimate at Completion**
  - EAC = BAC - CV or BAC / CI
EAC Original Estimate Approach

- Estimate at Completion: \( EAC = ACWP + ETC \)
- Estimate to Complete: \( ETC = BAC - BCWP \)
- \( EAC = ACWP + (BAC - BCWP) \)
- \( EAC = BAC - (BCWP - ACWP) \)
- \( EAC = BAC - CV \)
EAC Revise Estimate Approach

- ACWP / BCWP = 1 / CI
- ETC = WR * 1 / CI
- ETC = (BAC - BCWP) * 1 / CI
- EAC = ACWP + (BAC - BCWP) * 1 / CI
- EAC = ACWP + (BAC / CI) - (BCWP / CI)
- ACWP = BCWP / CI
- EAC = BAC / CI
- EAC = BAC * ACWP / BCWP
Example (after a month)

- **BCWS** = $7,456
- **BCWP** = $6,128
- **ACWP** = $7,400
- **CV** = $1,272
- **SV** = $1,328
- **CI** = 0.83
- **SI** = 0.82

**Original Estimate Approach**

\[
EAC = ACWP + BAC - BCWP = BAC - CV
\]

\[
= $31,000 - (- $1,272) = $32,272
\]

**Revised Estimate Approach**

\[
EAC = \frac{BAC}{CI} = \frac{$31,000}{0.83}
\]

\[
= $37,349
\]
Beware of Delays

- Financial, time indicators are necessary but not sufficient to alert to problems.
- In most cases of serious problems and “normal” reporting, the problem may be very serious by the time that it is noticed in the formal reports.
- Rapid qualitative judgment is often much more effective than delayed quantitative reporting.
Topics

- Monitoring cont’d
  - EVA (C/SCSC) Definitions and examples
  - Forecasting
- Project Control
  - General
  - Performance-adjustments
  - Target Adjustments
  - Problem diagnosis
Project Control: Managing Risks

- Monitoring alerts us to when there’s a problem
- Key elements of control
  - Problem diagnosis (discussed later)
  - Either
    - Plan correction (often political process)
    - Problem correction (often technical & managerial)
- All of the above must be undertaken *rapidly* to effectively control a project
  - Need to see if they correct the problem and react accordingly
  - Control without rapid monitoring highly handicapped
Value of Flexibility

- *Flexibility is primary defense against risk*
- Planning too tightly may highly complicate control
- Already Discussed: Flexibility value to the owner
  - (Expandability via clearspanning, larger # conduits,
- Flexibility in *construction* is key during control
  - Want enough “give” to change plans if necessary
  - Usual tradeoff: Overoptimizing for cost can limit flexibility
    - E.g. Equipment, materials, personnel
- Be careful on *value engineering* that limits flexibility!
The Project Control Process

1. **Initial Targets**
   - **Project Targets**
   - **Performance Targets**

2. **Performance Test**
   - **Performance Deficits and Surpluses**
   - **Error Signals**
   - **Control Actions**
     - **Project Changes**

3. **Forecasting**
   - **Forecasted Performance**
   - **Measured Performance**

4. **Target Changes**
   - **Target-Driven Control Loop**

5. **Performance-Driven Control Loop**
   - **Performance**
   - **Project**
Topics

- Monitoring cont’d
  - EVA (C/SCSC) Definitions and examples
  - Forecasting

- Project Control
  - General
  - Performance-adjustments
  - Target Adjustments
  - Problem diagnosis
Performance-Driven Control

- Project Targets
- Performance Test
- Error Signal Descriptors
- Control Actions
- Project Changes

Forecasting Performance

Measured Performance

Performance-Driven Control Loop

Performance-Driven Control

Performance Targets
Performance Deficits and Surpluses
Error Signals
Project Changes
Performance
Performance Driven Control

Planned Versus Actual Expenditures on a Project

- Planned Expenditure
- Actual Expenditure
- Revised Estimate of Future Expenditure
Performance-Driven Control Methods

- Awkward fact: Can typically only correct for one attribute of a problem at a time
  - Time
  - Cost
  - Quality
- Need to understand tradeoffs and triage
- Most “easy wins” will already be in place
  - Exception: Sometimes new information is available that can enable improved performance now
Attribute Linkages

Acceleration ⇒ $  
(Overtime, shift work,  
Rework, higher-end  
equipment, better crews etc.)

Slow progress ⇒ $  
Delayed occupation,  
Higher interest on  
const. loan  
Loss of tenants  
Opportunity cost

Cost ⇒ Schedule  
Difficulty in getting financing  
Default of parties  
Suspension of work  
Selection of poor quality workers

Quality level impacts speed of work,  
Level of rework

Need for rework imposes  
high expenses

High quality needs can lead  
to costly miscalculations  
on labor time

Trying to save $  
Can lead to substitution,  
lower quality  
workmanship

Quality problems result from  
overtime, shift work, new hires
Caveats on Overreacting

- When trying to correct, often bump up against other limiting factors
  - Space constraints
  - Skill set breadth
  - Hiring time
  - Morale
  - Coordination difficulties

- Often improvisation can lead to
  - Confusion
  - Cascading unanticipated effects

- “Job rhythm” and learning curves make big difference!
Schedule Performance Control

Project managers can use resources to increase work rate mainly in two ways:

1) adding new project resources (e.g., Schedule Crashing) and

2) reallocating available resources (e.g., Linear Scheduling Method),
Schedule Performance Control

- Change operating conditions by altering the location of the work
- Change operation conditions by altering the precedence, sequence, or timing of work
- Change the technology used
- Changes in the tools and methods
Project Acceleration I

- Multiple-shift work
  - Lack of coordination
  - Hiring
  - Environmental/safety constraints

- Overtime/Extended workdays
  - Fatigue
  - Lower morale
  - Rework
Project Acceleration II

- Using larger or more productive equipment
  - Training/learning curve
  - Procurement time
  - Space constraints
- Increasing # of workers
  - Training (takes time of most experienced!)
  - Space constraints
  - Hiring time
  - Lack of knowledge of processes
Project Acceleration III

- Using faster-installing materials
  - Procurement
- Alternate construction methods
  - Skill set
  - Learning curve
  - Unknown side-effects
Project Acceleration IV

- Summon on-call contractor
  - Learning curve
  - Friction between teams
  - Unknown personality situation
Activity Time-Cost Tradeoffs

- Frequently we have a tradeoff b.t. $ and time
  - “Time is money”
  - Can finish more rapidly if have
    - More highly skilled labor
    - More expensive equipment
    - More workmen
    - More highly paid (motivated!) labor
Total cost is non-monotonic: Sometimes using less time globally

NOTE: If activity time-cost curves are linear, then finding the optimal z
Recall: Earlier we discussed some resource time tradeoffs

- Resource leveling
- Resource scheduling

At that time, we considered activity atomic: We did not consider changing activity durations/resource use profiles

Time-curves often serve as a proxy for intra-activity resource reasoning
Time-Cost Tradeoffs: Key Concepts

- Two components (either or both)
  - Reduce duration for activities on *critical path*
    - Try to increase $ as little as possible in process!
  - *Reduce costs* on activities not on critical path
    - Often involves increasing duration – but want to keep off Critical path!

- Explicit activity time-costs tradeoffs examine direct, local activity costs only
  - Ignore (important) indirect costs of project extension
  - These are *global costs* that depend on the entire project duration rather than activity duration
Time-Cost Trade Off Curve

A single Activity trade off curve:

What duration would you choose?
Trading *Money for Time*

“Activity Crashing”

- Critical path tells us *time-limiting* activities
  - No benefit from reducing time of *all* activities up front – just those on *critical path*
  - NB: This is an important area in which CPM has contributed to construction understanding
    - Previously, many managers put effort into accelerating *whole project*
- Critical path may change as crashing changes activity durations
Time-Cost Algorithms

- If activity time-cost curves are linear, then finding the optimal duration of the project is a linear program (LP). If not, then it is an NLP.

- Common assumptions
  - Time-Cost tradeoff is convex
  - No binding resource constraints
  - “Normal” activity cost is lowest-cost point
Kelly & Walker Crashing Heuristic

1. Solve CPM with normal durations
2. For critical activities: Find marginal cost of crashing (i.e., additional cost of shortening duration 1 time unit)
3. Reduce by one time step the critical activity with the lowest marginal cost of crashing
4. Record resulting activity project duration and cost

NOTE: Good, but not necessarily optimal solutions

Problems? Concerns?
Issues with Heuristic

- What about resource constraints?
  - If our preferences were determined partly by resource constraints, we are no longer guaranteed to have a legal schedule!
  - The resulting schedule could have highly irregular (and thus costly) resource use

- Number of nodes multiples as more detailed cost tradeoffs required

- Monotonically decreasing but non-convex time-cost curves require different algorithm
Cost Performance Control

- Resource use, allocation again central
- Effective and timely cost control is crucial to ensuring the project cost performance. It should be an on-going process, taking into consideration the following:
  - Change resources to remove excess capacity
  - Change operating conditions to increase work efficiency and product quality
  - Change methods by outsourcing different operations
  - Re-price the work, equipment, or materials
  - Substitute with less expensive but acceptable materials or equipment
Trading *Time for Money*

**Slack Management**

- **Remember:** Time imposes extra indirect costs!

- **Slack Management:** when *budget is limited* during a certain time period, rescheduling the project by changing activity ‘timing’ and associated expenditure or income.

- **Activity Timing Change:** *Non*-critical activities first (having FF -> TF), then critical activities.

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Adapted from Pena-Mora 2003
Recall: Resource Leveling

- **Insight:** a more steady usage of resources leads to lower resource costs.
  - **Labor:** costs associated with hire, fire, and training
  - **Material:** storage requirement, planning and controlling efforts

- **Resource Leveling:** the reallocation of slack (TF or FF) in non-critical activities to minimize fluctuations in the resource requirement profile.
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  - Forecasting

- Project Control
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  - Performance-adjustments
    - Target Adjustments
    - Problem diagnosis
Target-Driven Control:
More Political Process
Topics

✓ Monitoring cont’d
  ✓ EVA (C/SCSC) Definitions and examples
  ✓ Forecasting

■ Project Control
  ✓ General
  ✓ Performance-adjustments
  ✓ Target Adjustments
  ■ Problem diagnosis