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)

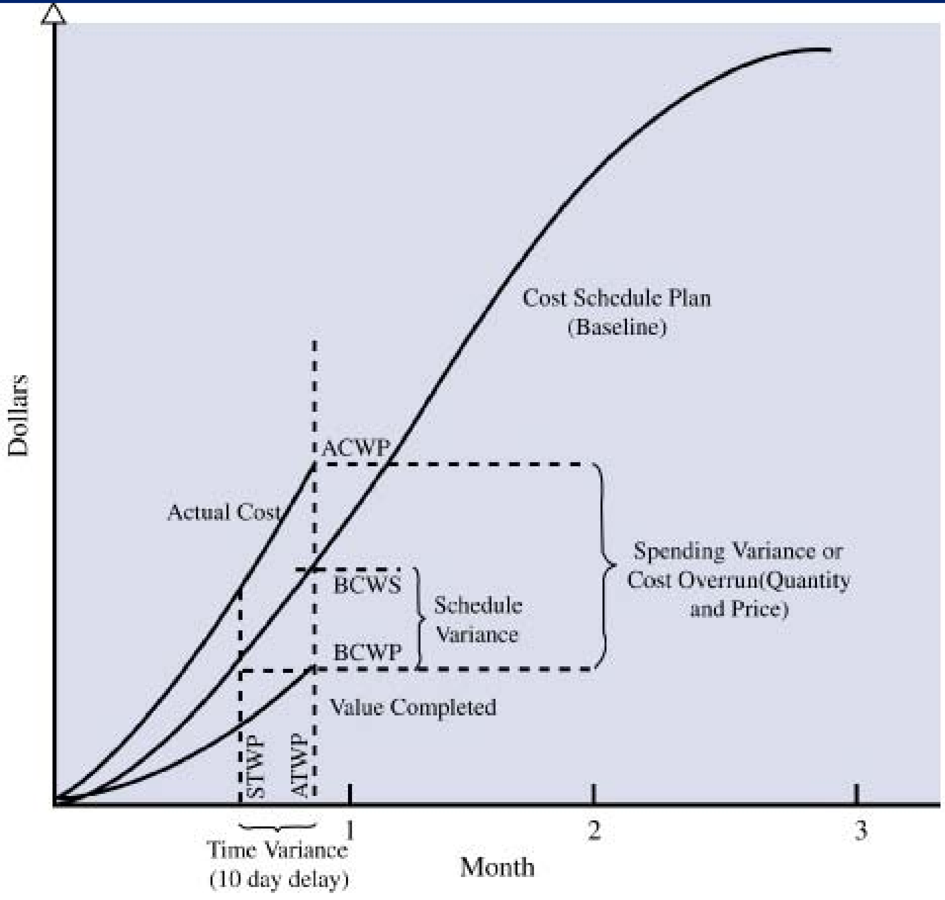
Time Variance

- *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) i

Resource Flow Variance

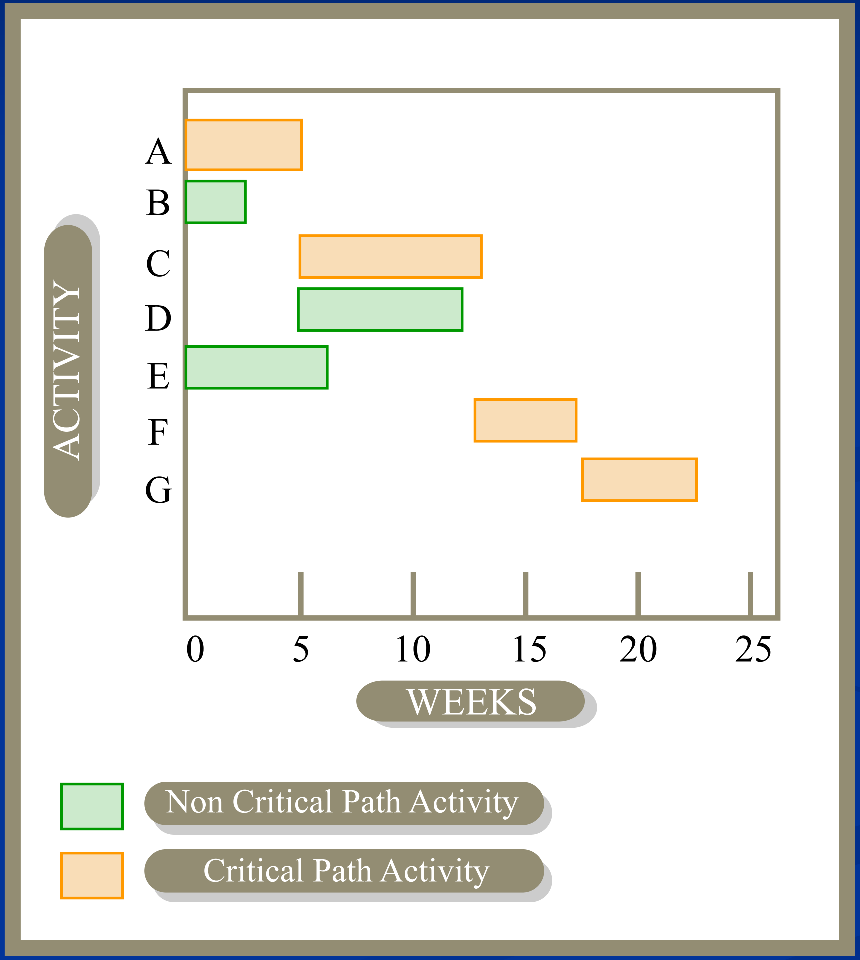
- *Compares* how much expecting to **spend** during this timeframe with what actually spent – regardless of how much work got done.
- Warning: Doesn’t indicate bad or good. e.g. = if
  - Going faster but more cheaply than expected
  - Going slower but more expensively than expected
- Resource Flow Variance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

Earned Value Chart



Earned Value Chart

Example: Gantt Chart Schedule



Example: Traditional Reporting

ACTIVITY	A	B	E
DURATION (WEEKS)	5	3	7
COST (IN $)	1,500	3,000	5,700
COST PER WEEK (IN $)	300	1,000	814

ACTIVITY	WEEK 1		WEEK 2		WEEK 3		WEEK 4	
	ACTIVITY STATUS	ACTUAL COST	ACTIVITY STATUS	ACTUAL COST	ACTIVITY STATUS	ACTUAL COST	ACTIVITY STATUS	ACTUAL COST
A	STARTED	$ 500	IN PROCESS	$ 1,000	IN PROCESS	$ 1,300	COMPLETED	$ 1,500
B	STARTED	1,000	IN PROCESS	2,000	IN PROCESS	2,500	COMPLETED	3,000
E	STARTED	814	IN PROCESS	1,500	IN PROCESS	2,500	IN PROCESS	2,900

Example: Earned Value Reporting

SUMMARY REPORT FOR WEEKS 1 - 4

ACTIVITY	A	B	E
ACTUAL COST (IN $)	1,500	3,000	2,900
BUDGETED COST (IN $)	300 × 4 = 1,200	3,000	814 × 4 = 3,256
WORK PERFORMED AS % OF WORK CONTENT	100	100	2/7 = 28.6

Example: Activity Analysis

ACTIVITY	BCWP
A	$ 1,500
B	$ 3,000
E	$ 1,628

ACTIVITY	ACWP
A	$ 1,500
B	$ 3,000
E	$ 2,900

ACTIVITY	BCWS
A	300 × 4 = $ 1,200
B	$ 3,000
E	814 × 4 = 3,256

Example: Variances

ACTIVITY	BCWP - ACWP = CV
A	$ 1,500 - $ 1,500 = $ 0
B	$ 3,000 - $ 3,000 = $ 0
E	$ 1,628 - $ 2,900 = -$ 1,272
	CUMULATIVE VARIANCE = -$ 1,272

ACTIVITY	BCWP - BCWS = SV
A	$ 1,500 - $ 1,200 = $ 300
B	$ 3,000 - $ 3,000 = $ 0
E	$ 1,628 - $ 3,256 = -$ 1,628
	CUMULATIVE VARIANCE = -$ 1,328

Variances II

ACTIVITY	STWP - ATWP = TV
A	5 - 4 = 1
B	3 - 4= -1
E	2 - 4= -2
	Cumulative Variance = -2

Example: Activity Indexes

Activity	$\frac{BCWP}{BCWS}$ = SI	$\frac{BCWP}{ACWP}$ = CI
A	$\frac{1,500}{1,200} = 1.25$	$\frac{1,500}{1,500} = 1$
B	$\frac{3,000}{3,000} = 1$	$\frac{3,000}{3,000} = 1$
E	$\frac{1,628}{3,256} = 0.5$	$\frac{1,628}{2,900} = 0.56$

Example: Project Indexes

The Aggregate Cost Index is:

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

$$CI = \frac{1{,}500 + 3{,}000 + 1{,}628}{1{,}500 + 3{,}000 + 2{,}900} = 0.83$$

Example: Earned Value Reporting

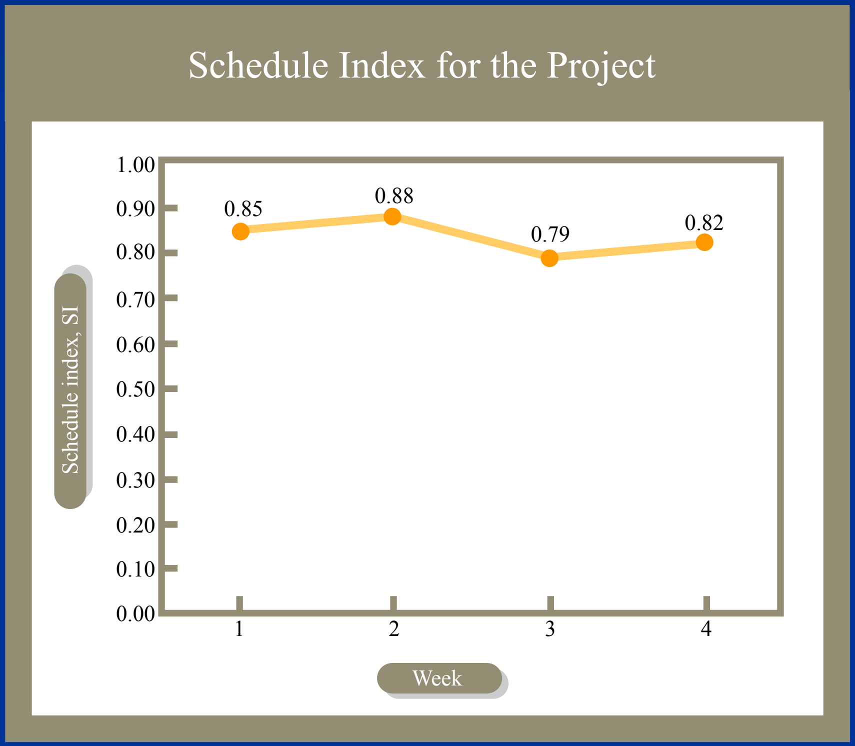
Values (in Dollars) of BCWS, BCWP, and ACWP for Weeks 1-4												
	Week 1			Week 2			Week 3			Week 4		
Activity	BCWS	BCWP	ACWP	BCWS	BCWP	ACWP	BCWS	BCWP	ACWP	BCWS	BCWP	ACWP
A	300	500	500	300	500	500	300	300	300	300	200	200
B	1,000	1,000	1,000	1,000	1,000	1,000	1,000	500	500	0	500	500
E	814	300	814	814	400	686	814	500	1,000	814	428	400
	2,114	1,800	2,314	2,114	1,900	2,186	2,114	1,300	1,800	1,114	1,128	1,100

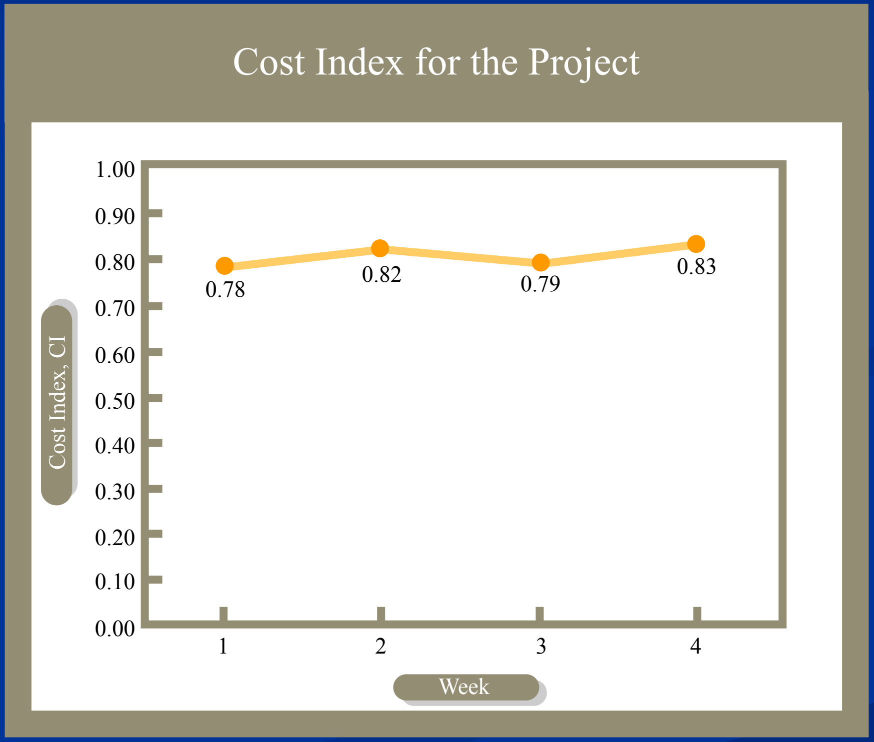
Example: Earned Value Analysis

Values of SI and CI for Weeks 1-4

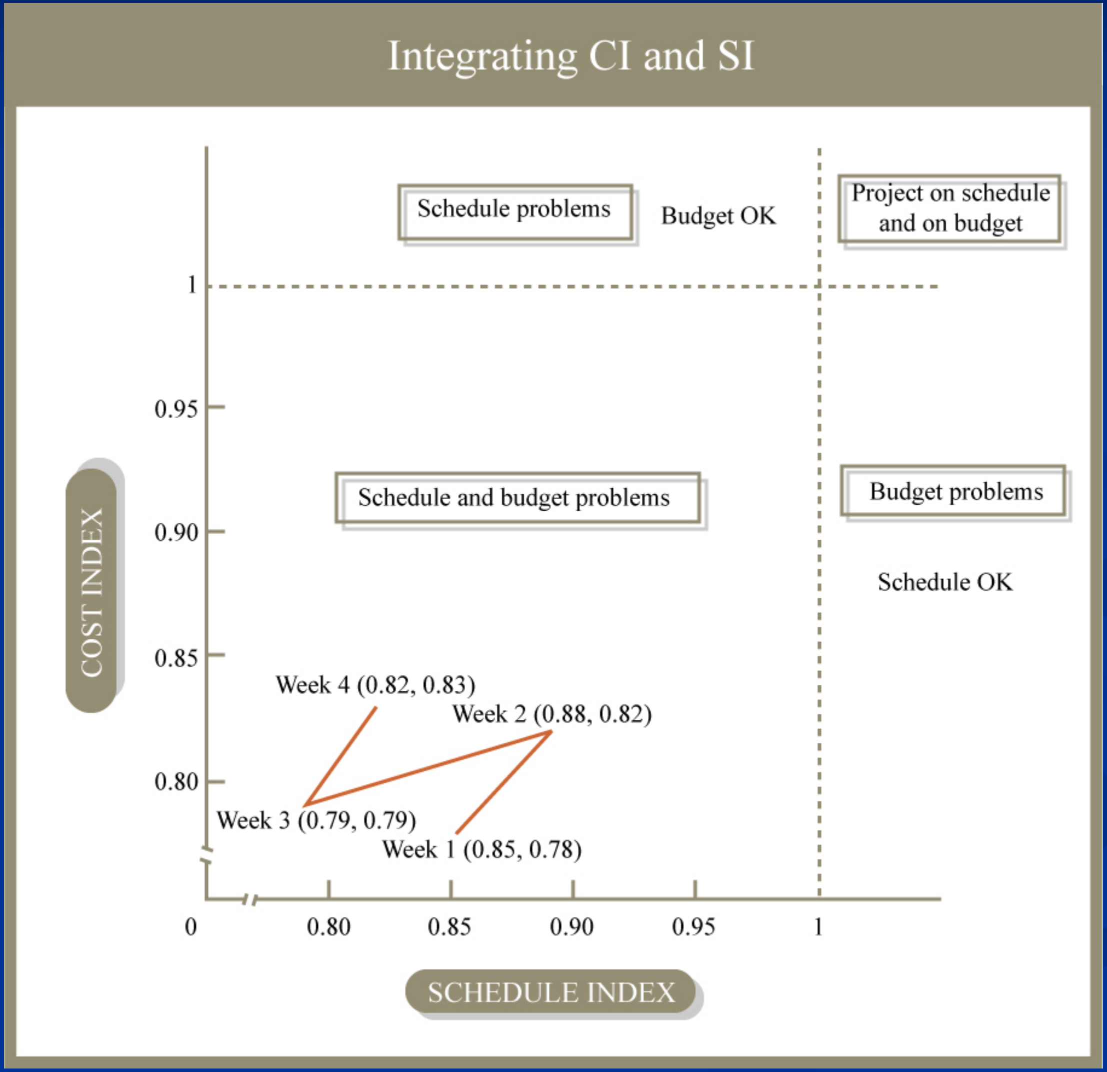
Week	BCWS ($)	BCWP ($)	ACWP ($)	$CI = \frac{BCWP}{ACWP}$	$SI = \frac{BCWP}{BCWS}$
1	2,114	1,800	2,314	0.78	0.85
2	4,228	3,700	4,500	0.82	0.88
3	6,342	5,000	6,300	0.79	0.79
4	7,456	6,128	7,400	0.83	0.82

Example: Schedule and Cost Index





Example: Integrating CI and SI



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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 = BAC / CI = $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

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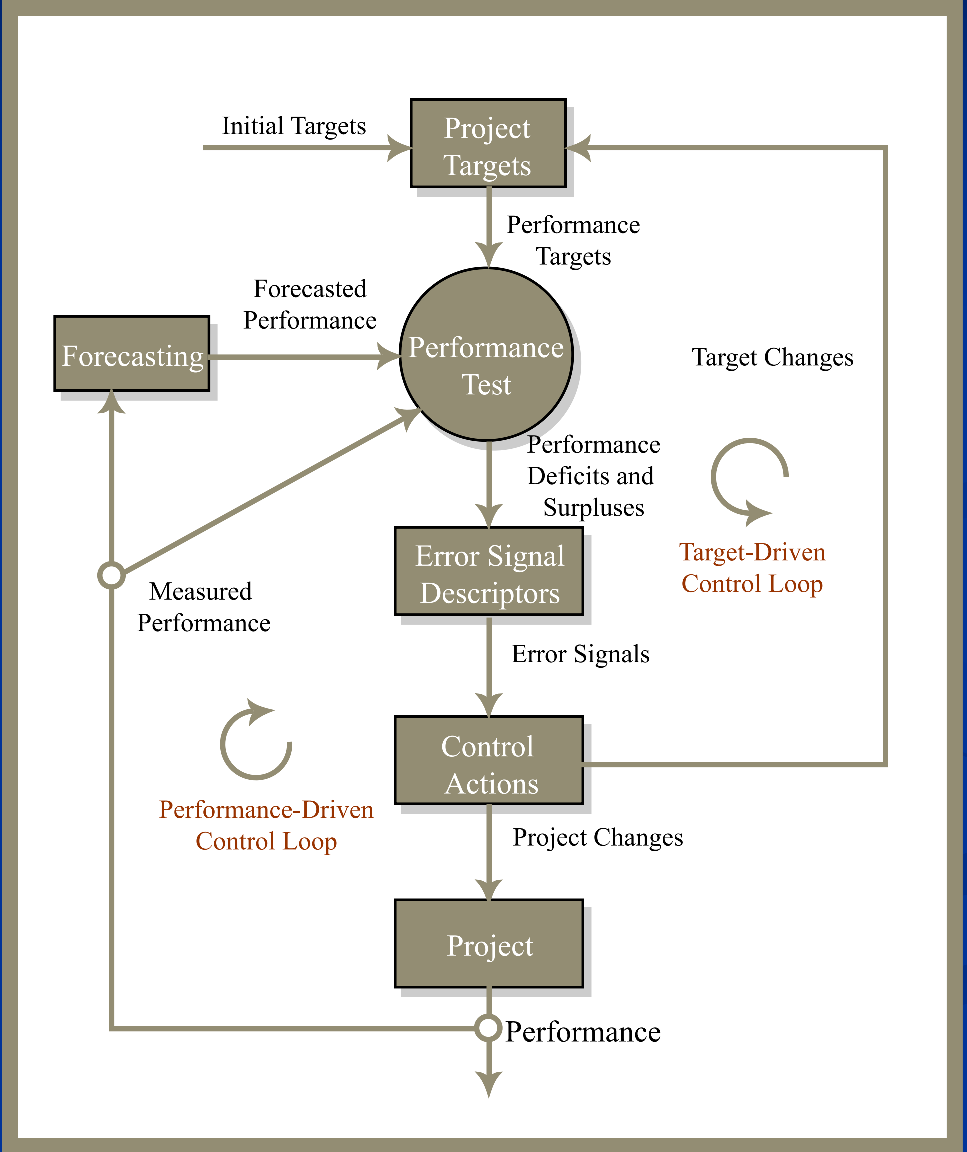
Project Control: Managing *Risks*

- 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



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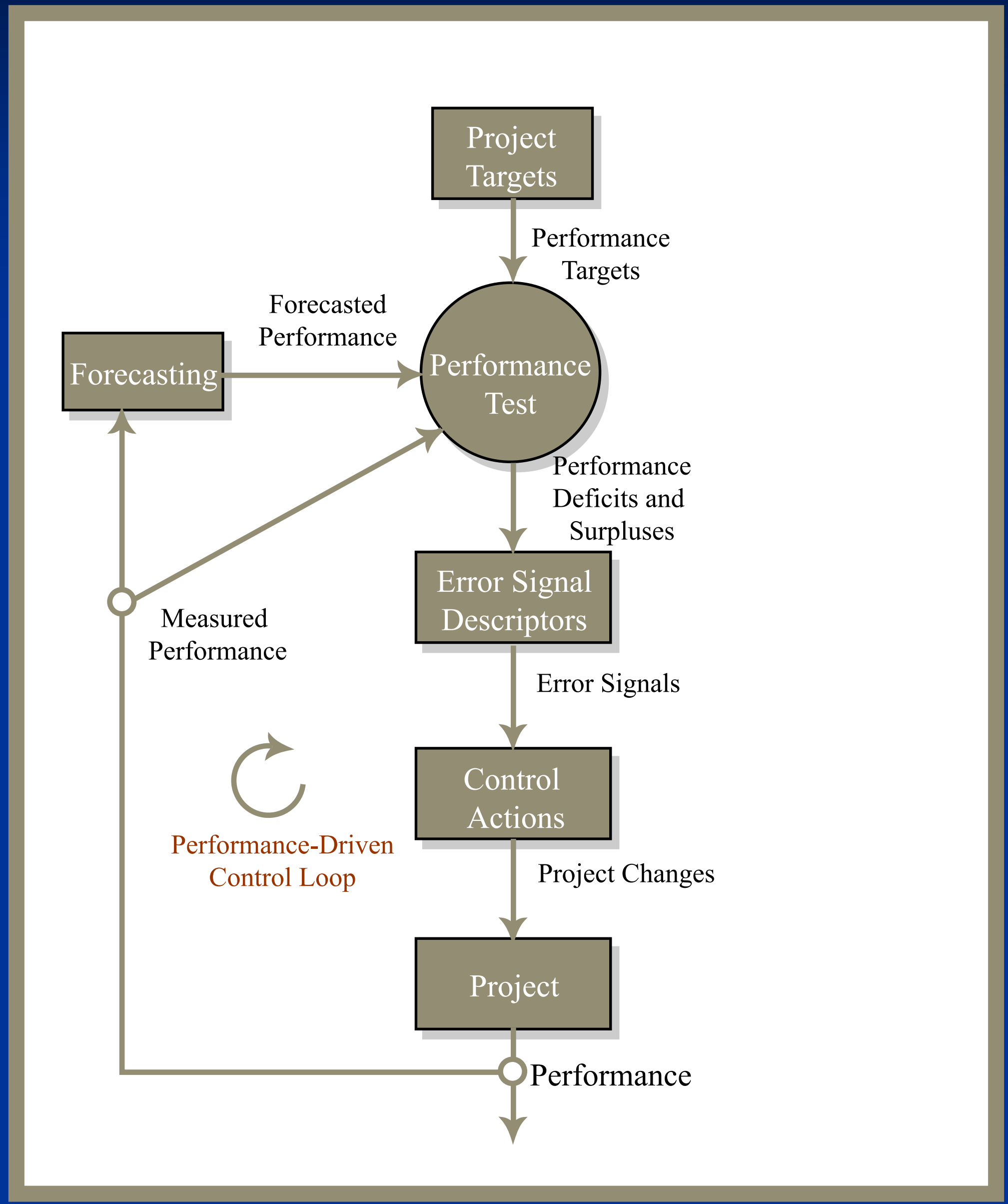
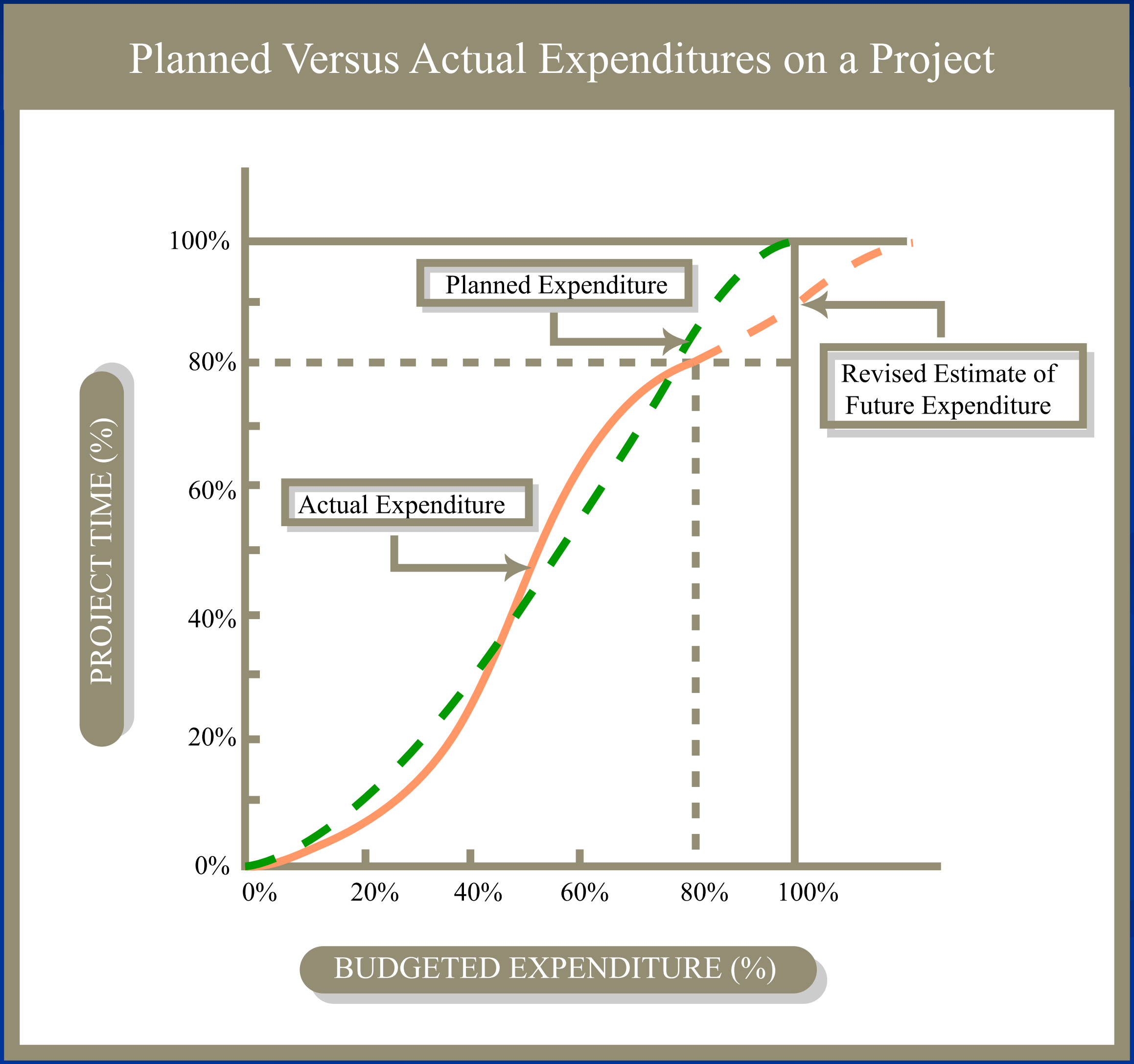
Performance-Driven Control



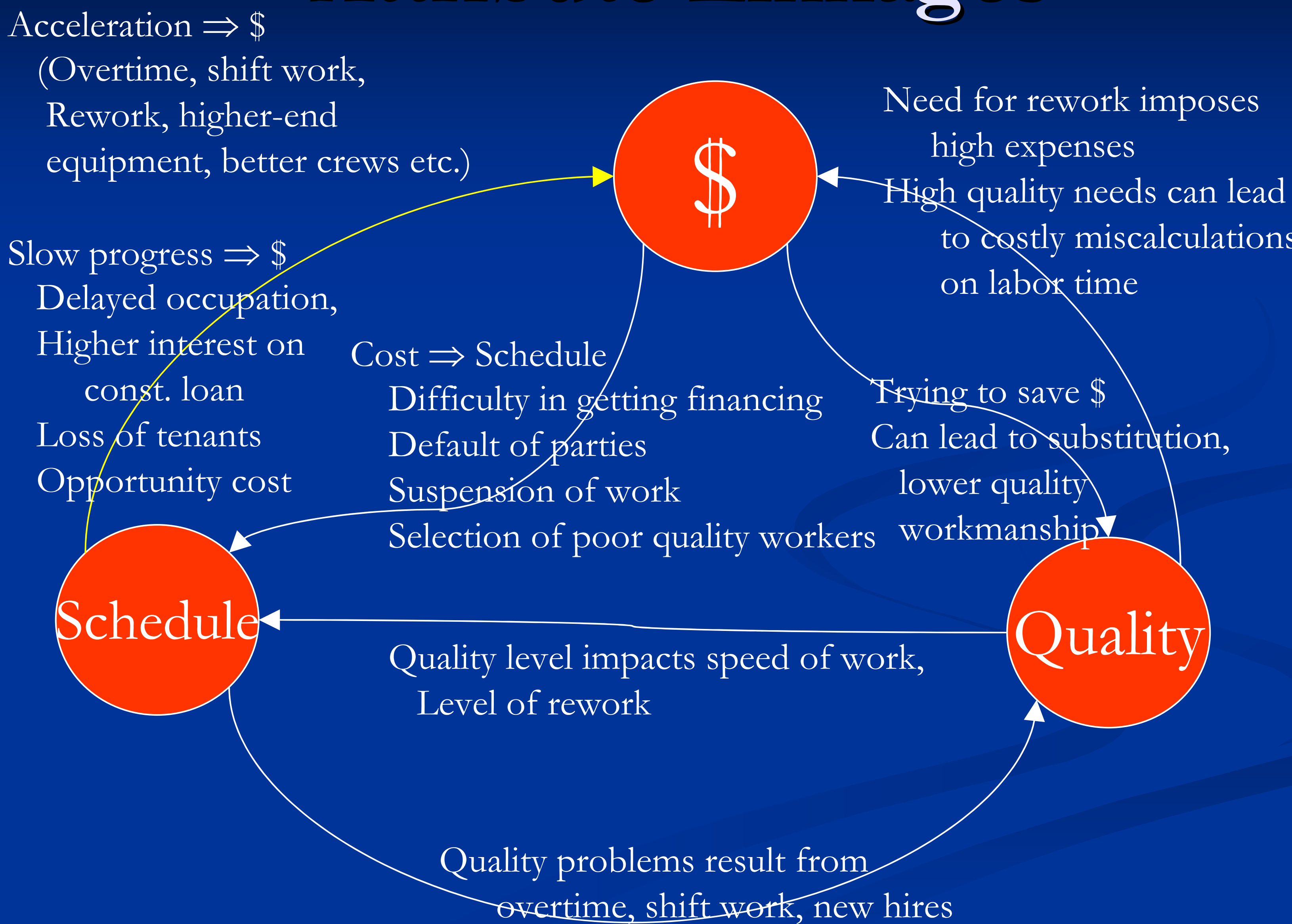
Performance Driven Control



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



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 (eg., *Schedule Crashing)* and

2) reallocating available resources (eg., *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

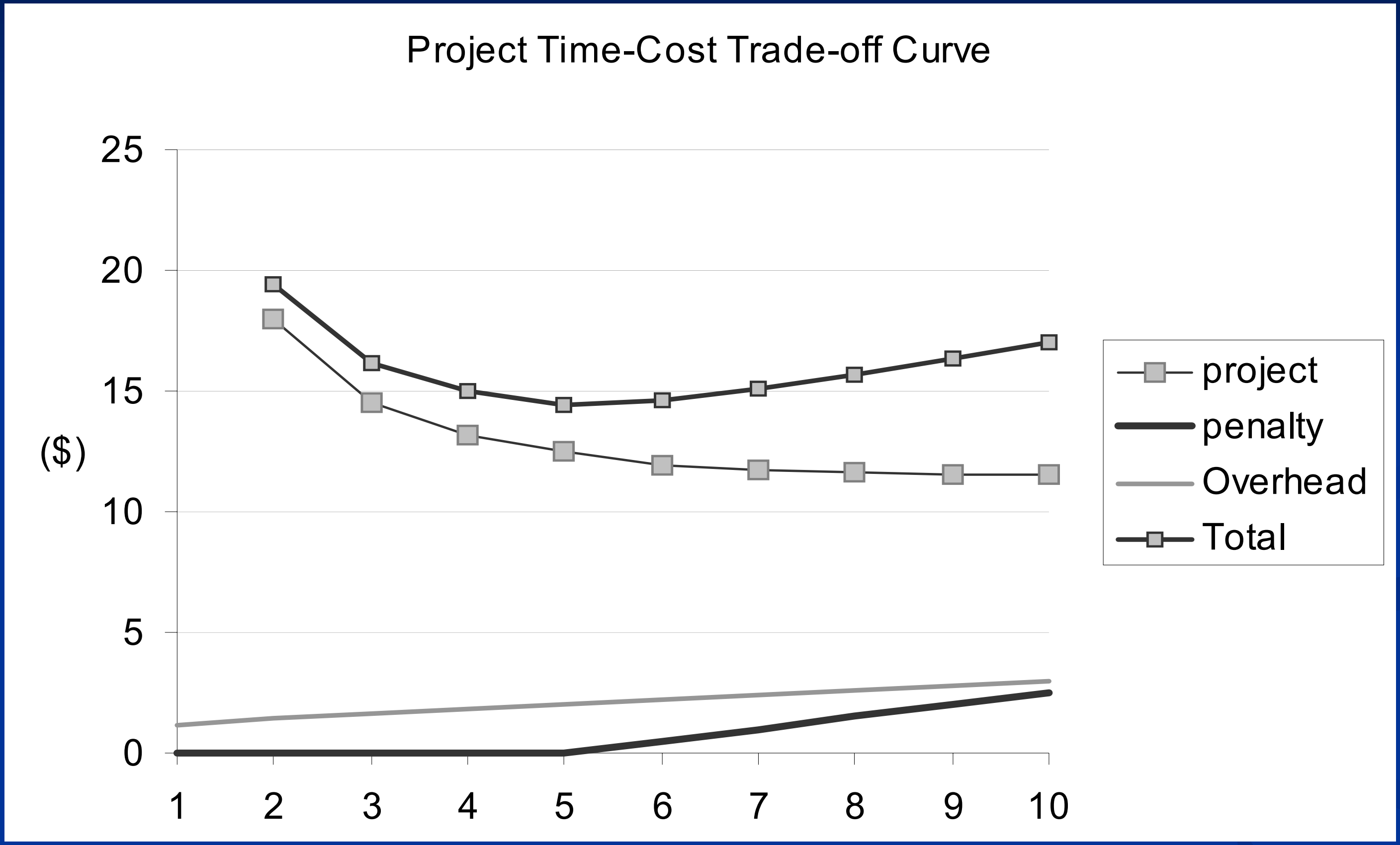
Project Acceleration IV

- 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

Project Time-Cost Tradeoff



Total cost is non-monotonic: Sometimes using less time globally
NOTE: If activity time-cost curves are linear, then finding the optimal z

Link to Earlier Topic: Resource Scheduling

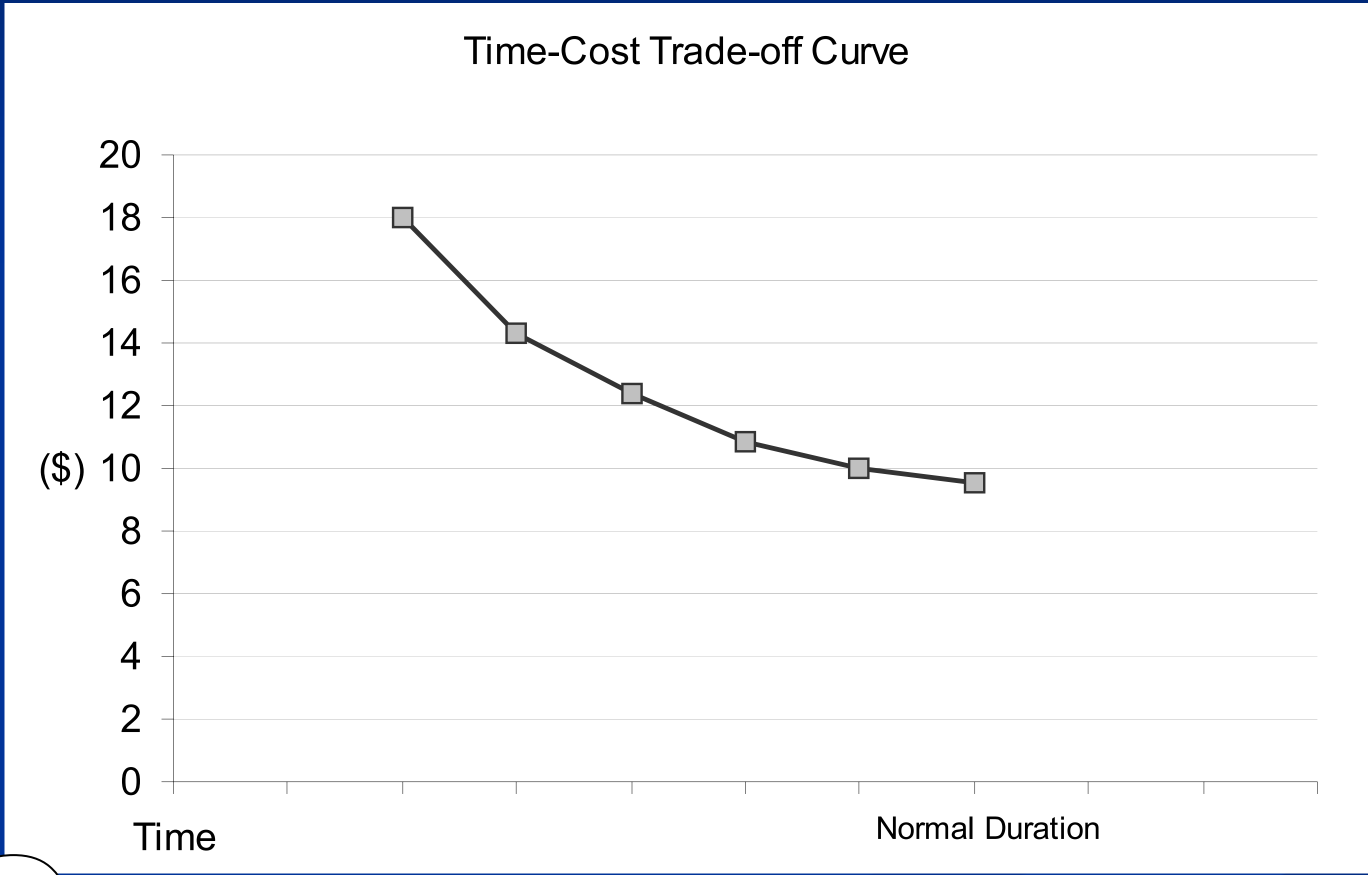
- Recall: Earlier we discussed some *resource* time tradeoffs
  - Resource leveling
  - Resource scheduling
- At that time, we considered activity atomic: We did *not* consider changing activity durations/resource use profiles
- Time-curves often serve as a proxy for intra-activity resource reasoning

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
5. Repeat [3] until another path becomes critical.
6. Repeat [1] until project cost increases.

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.

Activities having Free Float → Activities having Total Float → Activities on Critical path

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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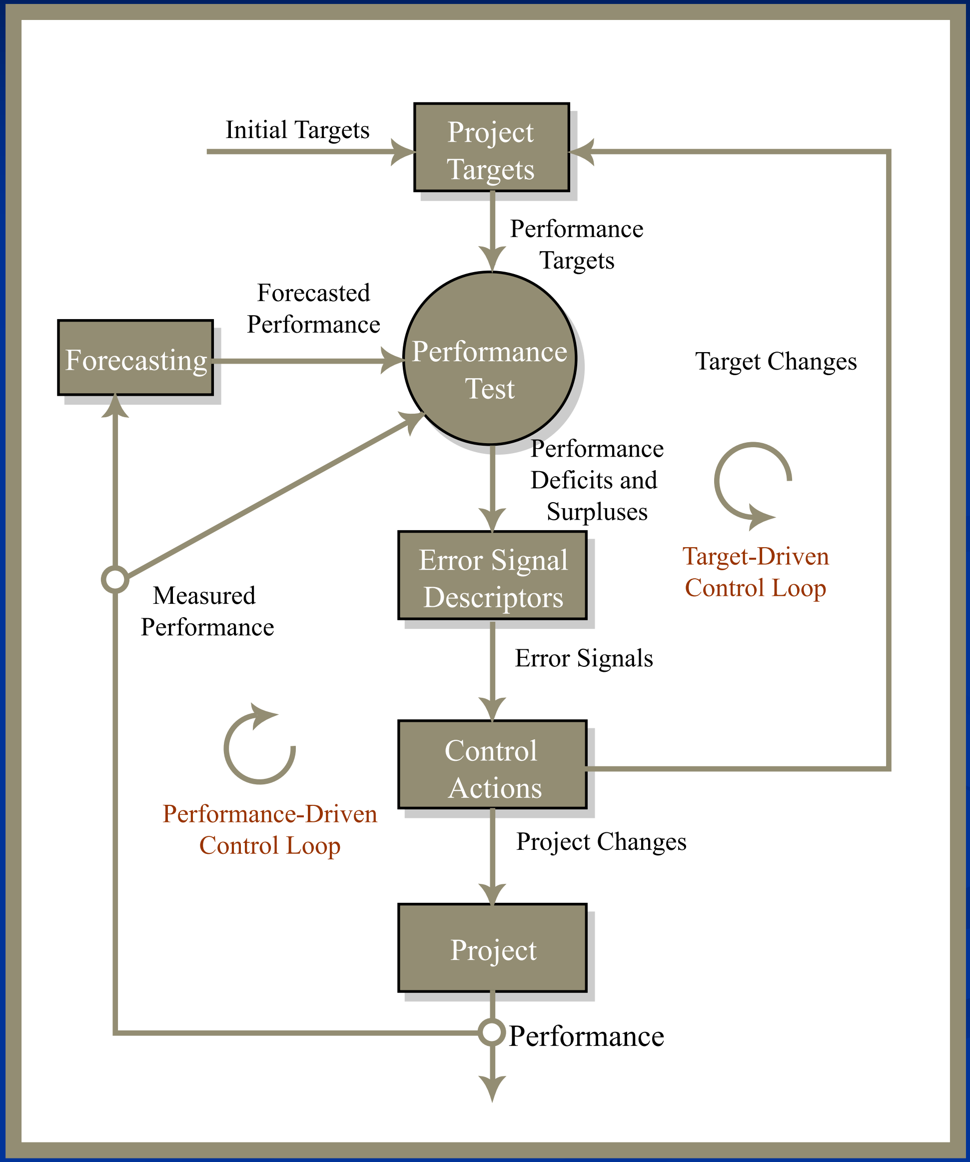
Target-Driven Control: More Political Process



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