Basics of Cost and Schedule Monitoring

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Announcements

- Tuesday field trip
  - Leave at 4pm
  - At existing platform 4:15pm
- Problem set grading: ps1 ongoing, ps2 end of this week
- TP3 out today
- Questions on problem set?

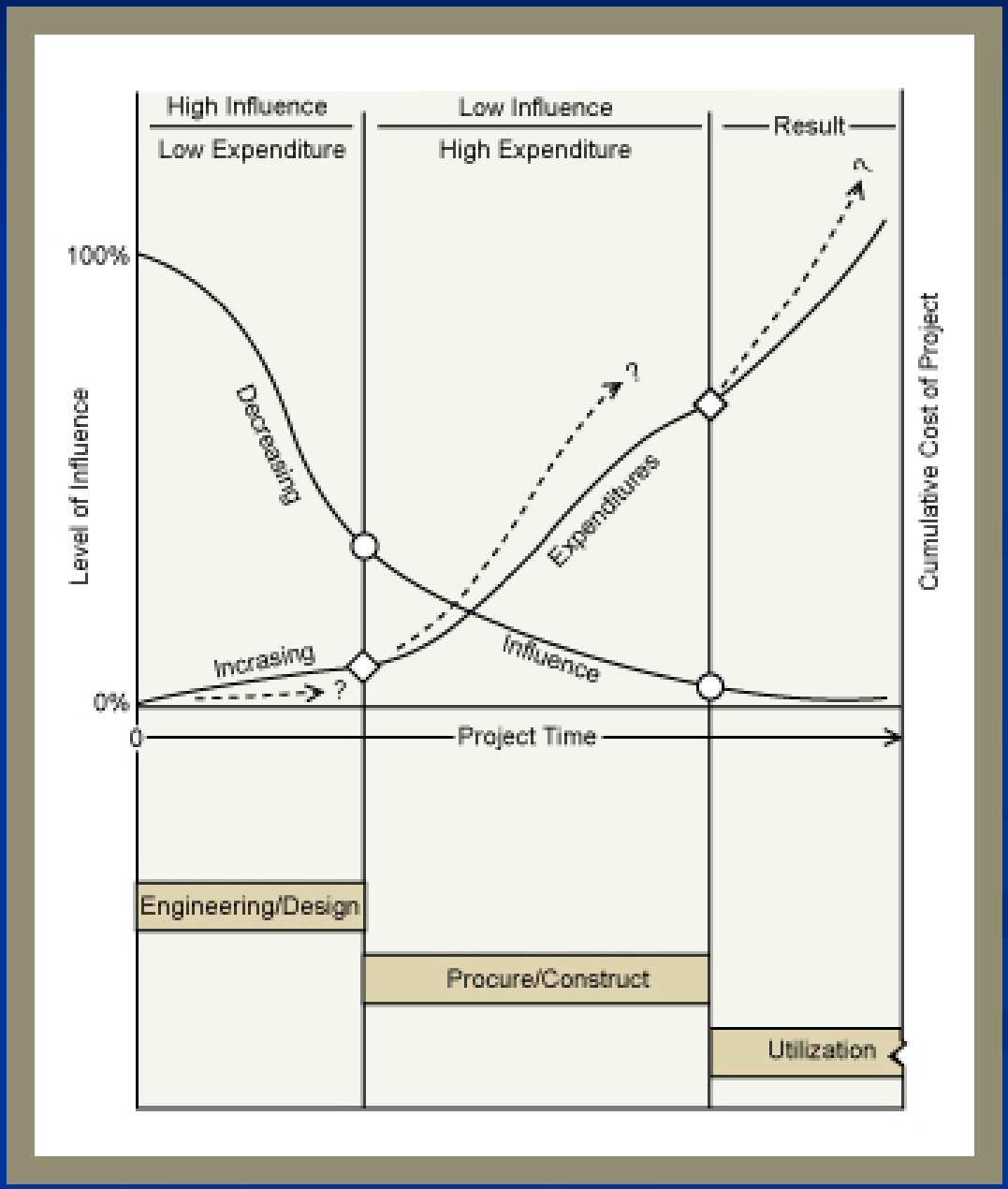
Topics

- Monitoring and Scheduling: The Big Picture
- Monitoring
  - Links to previous topics
  - Key components in realizing effective monitoring
  - Measurement: Basics of cost and schedule tracking
    - Components of Measurability
    - Collecting information
  - Performance Metrics
  - Forecasting
  - Quality monitoring

Monitoring and Control: Two Parts of a Feedback System

- Goal is to *detect* and *correct* deviation from desired
  - Budget
  - Schedule
  - Quality
- Detection: Monitoring
- Correction: Control
  - Much harder than monitoring!
  - Bring project performance back in line with plans
  - Typical: Bring plans in line with performance

Growing Expenditures, Declining Control



Definitions

Monitoring: Project Monitoring is the set of procedures and management practices used to collect information about the performance achieved or forecasted in a project and the developing organization, based on a set of performance metrics.

Performance Analysis: The process of determining performance variances based on monitored or forecasted performance.

Definitions

Project Control: The purpose of project control is to adjust the project to meet its goals by assessing the performance of the project, analyzing the causes of performance problems, designing changes to address problems that are determined to need attentions, and implementing those changes through control actions. Project control is distinguished from project planning in two important ways: 1) project control yields a set of designs, decisions, and actions, whereas project planning yields a design, and 2) project control is a real time process during the implementation, not before the implementation begins.

Critical Role of a Feedback System

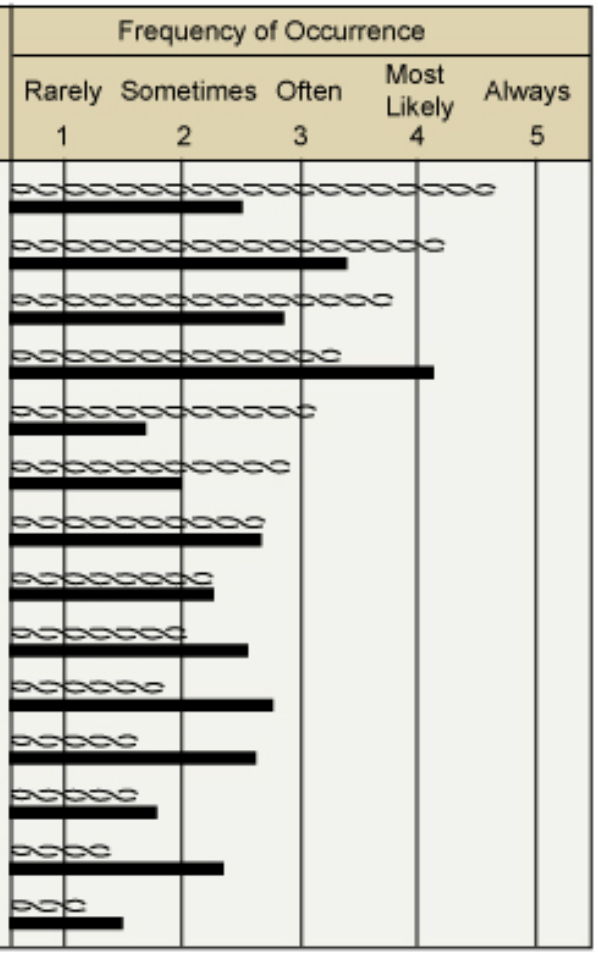
- Totally static planning is a (useful!) *fiction*
- Many factors make deviations *standard e.g.*
  - Physical: Weather, diff. geotechnical conditions,…
  - Early or late delivery of procured items
  - Changes in owner needs
  - Differences in productivity
  - Community opposition/Concerns abutting buildings
  - Mistakes in planning
- Even within slack, have resource constraints
- Morale often dependent on good planning

Perceived Challenges for Effective Monitoring & Control

Rank Order	Challenge	Frequency
1	Coping with end-date-driven schedules	85%
2	Coping with resource limitations	83%
3	Communicating effectively among task groups	80%
4	Gaining commitment from team members	74%
5	Establishing measurable milestones	70%
6	Coping with changes	60%
7	Working out project plan agreement with team	57%
8	Gaining commitment from management	45%
9	Dealing with conflict	42%
10	Managing vendors and subcontractors	38%
11	Other challenges	35%

Problems Ranked by General and Engineering Managers

Rank by General Managers	Rank by Engineering Managers	Reason or Problem
1	10	Insufficient Front-End Planning
2	3	Unrealistic Project Plan
3	8	Project Scope Underestimated
4	1	Customer/Management Changes
5	13	Insufficient Contingency Planning
6	12	Inability to Track Progress
7	5	Inability to Detect Problems Early
8	9	Insufficient Number of Checkpoints
9	4	Staffing Problems
10	2	Technical Complexities
11	6	Priority Shifts
12	10	No Commitment by Personnel to Plan
13	7	Sinking Team Spirit
14	14	Unqualified Project Personnel



Directly observed reasons for schedule slips and budget overruns. Solid bar, engineering managers' ranking; twisted bar, general managers' ranking.

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Links to Earlier Topics: Scheduling

- Scheduling provides us with a yardstick to help us understand what to expect over time
  - Work Progress
  - Expenditures
  - Without some scheduling, we would have nothing against which to compare progress!
- Monitoring ⇒ Scheduling: Must reformulate schedule to reflect discrepancies!

Schedule Updates from Monitoring

- New estimates for activity
  - Costs
  - Durations
  - Resource availability
- Must compute new critical path
  - May lead to changed monitoring priorities
- NB: A schedule that does not get updated to reflect in-field conditions is
  - Unlikely to be used
  - Dangerous if used

Project Plan is the Foundation of Effective Monitoring

- Plan Ahead
- Involve Project Team Members during the Planning
- Define Specific Task Responsibility
- Obtain Commitment
- Assure Measurability

Tie-Ins with Earlier Topics: Estimation

- Cost Estimation helps us understand cost implications of activities
  - Often this is folded into the schedule
  - Without estimation, we also would have nothing against which to compare progress!
- Often used to prepare initial budget
  - Problems
    - Different level of granularity
    - Estimate oriented towards outside reporting

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Components of Effective Monitoring

- Representative Performance Metrics (established at planning phase)
- Cost & Schedule Milestones should be well-defined and clearly approved/rejected.
- Reporting Schedule (perhaps of variable Δt's)
  - Financial importance of activity
  - Activity criticality
  - Rate of work
  - Difficulty of work
- Management Scheme organized for honestly and accurately identifying and reporting performance
- Involvement of responsible and knowledgeable people in the reporting scheme
- Project Reviews (walkthrough's & inspections)
- Project Audits

Characteristics of Effective Control System

Characteristics of Effective Management Cost Control Systems

BUDGETS

- Budgets are broken into cost elements, such as activities broken into time phases, showing expenditure profiles
- They are estimated by resposible individuals
- Budgets are associated with known risk factors and uncertainties
- Budgets are agreed on between a resposible manager and upper management
- Budgets are made in constant dollars, hence providing for adjustment for inflation or overhead changes.

ACTIVITIES

- Activities are part of a clear and sytematic cost model (e.g, the WBS)
- They are clearly defined in terms of the work to be performed, results, timing, and individual resposibilities
- Activities are agreed on by the individual responsible regarding the work, timing, and budget
- They are measurable milestones and deliverables
- Activities are associated with a singular controlling authority, resposible for results
- Activities are visible throughout the project and the organization, and there is senior management involvement
- Activities are reflective of overall project objectives
- Activities are regularly reviewed by management
- Activities are monitored to detect early problems regarding task accomplishment and integration.

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Measurement of Project Progress

- Traditional measures of project "progress" are based on resources consumed
  - Time spent
  - Money spent
- What is the problem with this?

Effective Measurement

- Most effective progress measurements are carried out not on project *inputs* ($, labor, time, etc.) but on project *outputs*
  - Goal: Measure *progress towards completion*
- Inputs are easy to measure; how do we measure *outputs*?
  - Where possible, divide activities into stages
  - Define clear-cut milestones
  - Keep track of costs, labor, time on per-activity basis

Characteristics of Well Defined Milestone

- Clearly Defined Entity
- Verifiable Parameters for Each Delivery Item
- Clear Relationship to Program Management Plan
- Well Defined Responsible Organization or Individual

Steps for Establishing Measurable Milestones

Steps in Establishing Measurable Milestones

Planning Activity and Responsible Organization or Individual	Results
1 Start with customer and/or sponsor requirement and develop program management plan. (Customer and program office responsible)	Project/system specifications, statement of work, work breakdown structure, project management subplans, budget, schedule, project team roster
2 Define key milestones throughout the life cycle of the project. (Program office or engineering manager responsible)	Milestone schedule, dates for design review, tests, prototypes, installations, documentation, training
3 Define deliverable items for each milestone. (Engineering manager and task leader responsible)	List of deliverables (for example, milestone for design review: diagrams, tradeoff analysis, make-buy decisions, system specifications, bill of material, safety plan, test plans)
4 Define specific parameters for each deliverable item. (Task leader responsible)	Statement of work, task authorization, specifications, vendor test, sign-off, report, method
5 Establish modular cost budgets for each key milestone; try to establish cost accounts for each deliverable item. (Engineering manager and task leader responsible)	Budgets, elements of cost task budgets such as: Tasks A-D: deliverable 1, $12,000. Tasks E-K: deliverable 2, $ 50,000. Tasks L-P: deliverable 3, $8,000.

Measuring Progress w/i Activity

- Units completed (units task specific)
  - ft Rebar laid, # columns placed, yd^3 earth moved, panels mounted, ft^2 drywall placed, ft piping installed
- Incremental sub-task milestones
  - Each associated with agreed-upon fraction of work
  - May be weighted if going on simultaneously
- Supervisor subjective opinion
- Binary start-finish
- Input measure: $ incurred/estimated total $

Key Component: Linking Activities and Count Accounts

- Recording granularity *critical* – limits what can be understood with the data
- Many-to-many mapping between
  - Cost categories
  - Activities
- Traditional operational accounting would just have cost code with type of item being charged
- Ways of addressing
  - More detailed cost code (incorporating activity)
  - Apportioning of ambiguous costs according to non-ambiguous

Tradeoffs in Cost Granularity

- More detailed advantages
  - Preserves option of finer investigation
  - Can allow for quicker
    - Response to deviations
    - Determination if control strategies helping
- Less detailed advantages
  - Less work for staff
  - Faster recording
  - Lower likelihood of error/compliance failure

Means of Collecting Data

- Foremen note progress on timesheets
  - (Implicit): Team
  - Cost category for item
  - Square footage for progress estimate (if lucky…)
- Payroll clerk enters timesheets in office
- Additional managerial attention can be applied for important activities

Review: Cost Breakdown Structure

- Canonical way of accounting for costs in the project
- Assigns accounts for different types of expenditures
- Should permits tracking expenditure by activity (work item)
- Often includes WBS-based characterization (e.g. CSI Masterformat)

Managerial vs. Financial Accounting

- Managerial ("Cost") Accounting
  - Reporting to managers for strategic planning
  - Operational use
- Financial accounting
  - Typically for outside parties (owners, taxes, regulators, …)
  - Trans. in general ledger (double-entry bookkeeping)
  - Familiar income and balance-sheets
  - Many "accounting fictions" to systematically account for flows

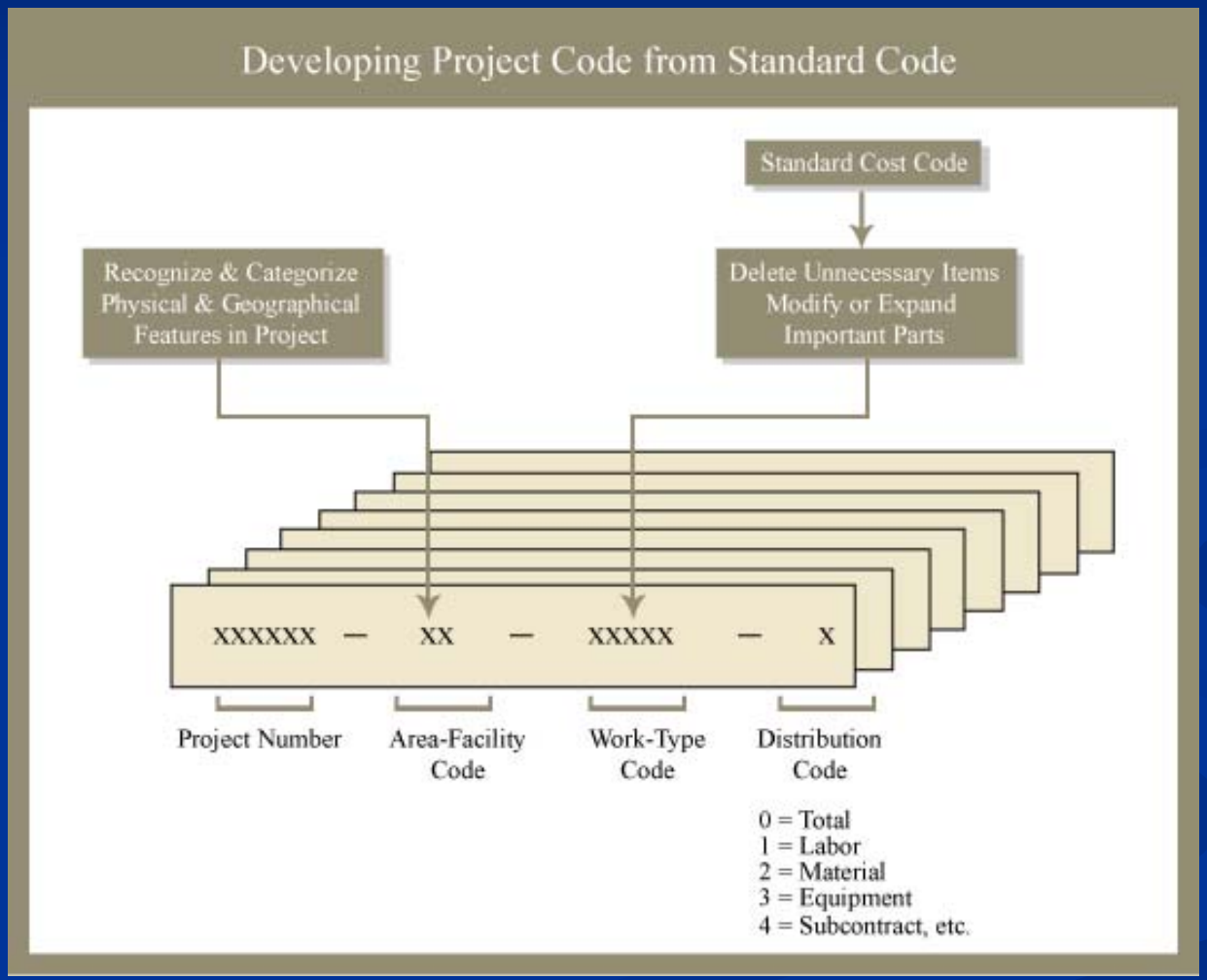
Recall: Cost Code

- Mirrored by cost hierarchy
- Commonly include standardized and project components
  - Project id (often has useful info to avoid lookup)
    - Often omitted from internal project references
  - Area-facility code (geographically distributed projects, or areas of a facility *unique to project*)
  - Work-type code: WBS May be standard code (e.g. CSI Masterformat) if uniform across projects
  - Distribution code: Cost type associated with work
    - (e.g. Materials, Equipment, Labor, Subcontract, etc.)

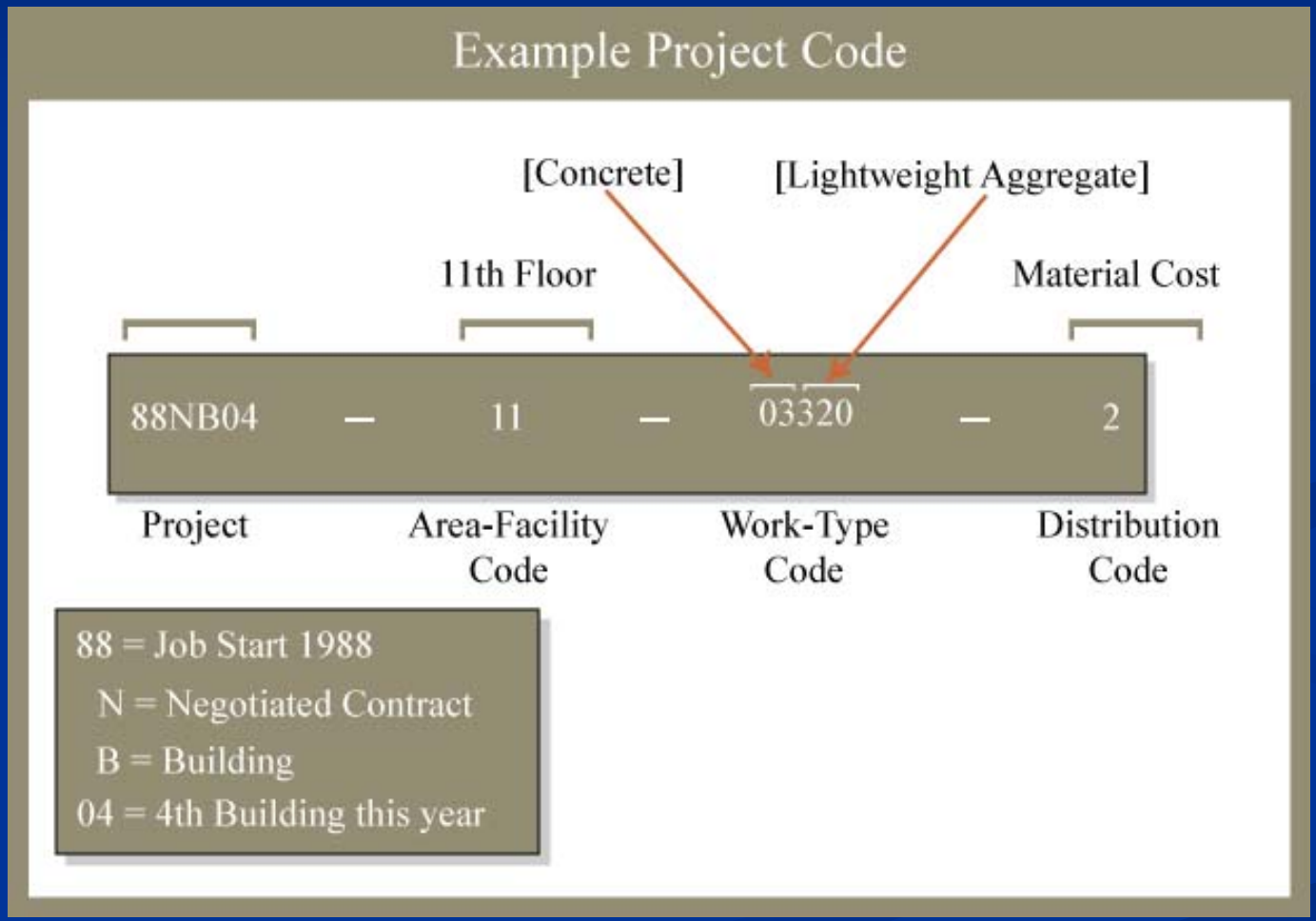
Illustrative Set of Project Cost Accounts

201□	□	□			Clearing and preparing site
202□	□	□			Substructure
□	202.1□□				Excavation and shoring
□	202.2□□				Piling
□	202.3□□				Concrete masonary
□	□	202.31□	□		Mixing and placing
□	□	202.32□	□		Formwork
□	□	202.33□	□		Reinforcing
203□	□	□			Outside utilities (water. gas, sewer, etc.)
204□	□	□			Superstructure
□	204.1□□				Masonary Construction
□	204.2□□				Structural steel
□	204.3□□				Wood framing, partitions, etc.
□	204.4□□				Exterior finishes (brickwork, terra cotta, cut stone, etc.)
□	204.5□□				Roofing, drains, gutters, flashing, etc.
□	204.6□□				Interior finish and trim
□		204.61□	□		Finish flooring, stairs, doors, trim
□		204.62□	□		Glass, windows, glazing
□		204.63□	□		Marble, tile, terrazo
□		204.64□	□		Lathing and plastering
□		204.65□	□		Soundproofing and insulation
□		204.66□	□		Finish hardware
□		204.67□	□		Painting and decorating
□		204.68□	□		Waterproofing
□		204.69□	□		Sprinklers and fire protection
	204.7□				Service work
□		204.71□	□		Electrical work
□		204.72□	□		Heating and ventilating
□		204.73□	□		Plumbing and sewage
□		204.74□	□		Air conditioning
□		204.75□	□		Fire alarm, telephone, security, miscellaneus
205□	□				Paving, curbs, walks
206□	□				Installed equipment (elevators, revolving doors, mail chutes, etc.)
207□	□				Fencing

Cost Code Illustration



Example Project Code



Reporting

- Often delayed (minimizing delay critical in effectiveness of feedback systems)
- Selective reporting widely used: Report only problematic items
- Frequent reporting for
  - Important (e.g. high cost)
  - Uncertainty (Unfamiliar procedure, …)
  - Critical
  - Scope

Reporting: Example 1

A Job Status Report

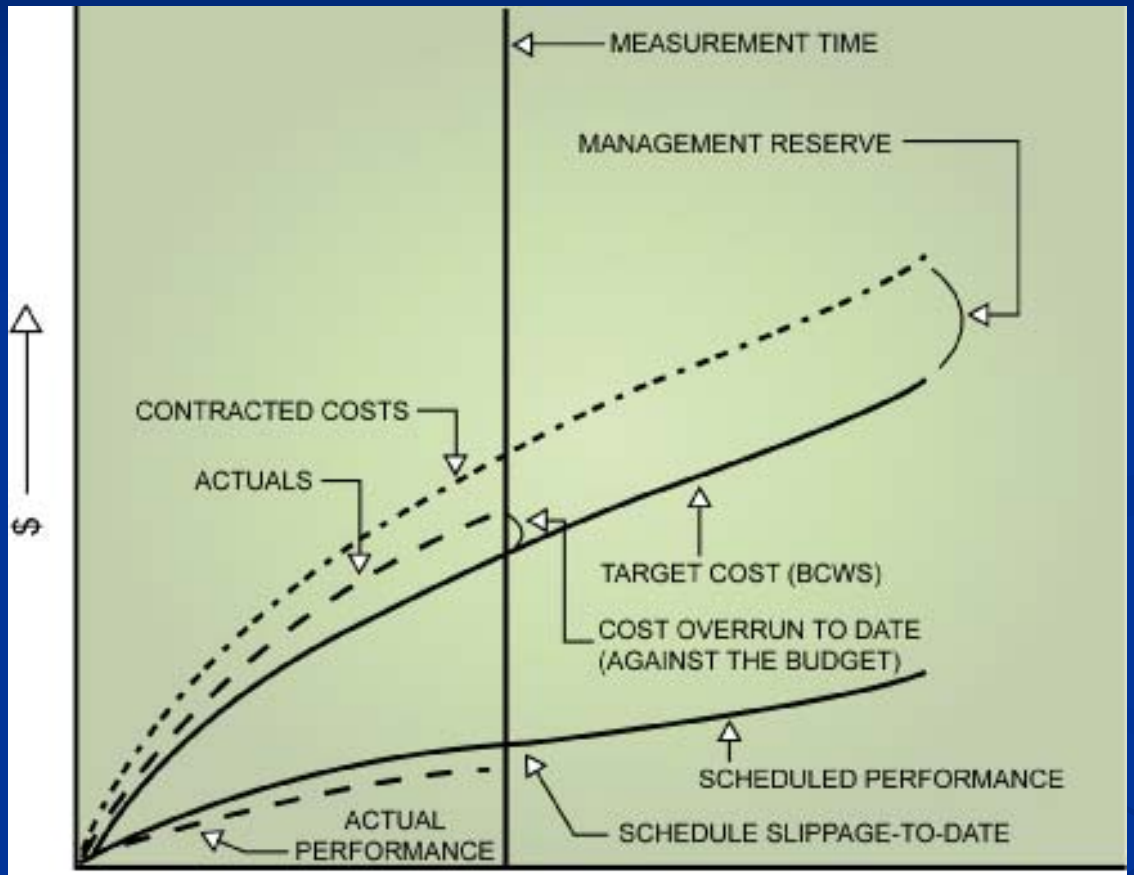
Factor	(1) Budgeted Cost	(2) Estimated Total Cost	(3) Cost Committed	(4) Cost Exposure	(5) Cost to Date	(6) Over or (Under)
Labor	$ 99,406	$ 102,342	$ 49,596	—	$ 52,746	$ 2,936
Material	88,499	88,499	42,506	45,993	—	0
Subcontracts	198,458	196,323	83,352	97,832	15,139	(2,135)
Equipment	37,543	37,543	23,623	—	13,920	0
Other	72,693	81,432	49,356	—	32,076	8,739
Total	496,599	506,139	248,433	143,825	113,881	9,540

Reporting: Example 2

A Cash Flow Status Report ($)

COSTS 7/02	CHARGES 8,754,516	ESTIMATED 65,863,092	% COMPLETE 13.292	PROJECTED 66,545,263	CHANGE 682,171
BILLINGS 7/01	CONTRACT 67,511,602	GROSS BILL 9,276,621	% BILLED 13.741	PROFIT 966,339	
PAYABLES 7/01	PAID 6,719,103	OPEN 1,300,089	RETENTION 391,671	LABOR 343,653	TOTAL 8,754,516
RECEIVABLE 7/02	NET BILL 8,761,673	RECEIVED 7,209,344	RETENTION 514,948	OPEN 2,067,277	
CASH POSITION	PAID 7,062,756	RECEIVED 7,209,344	POSITION 146,588		

Integrated S-Curve



Integrated Cost/Schedule System

Exploratory Breakdown

- Business intelligence software
- Dynamic breakdown by category
- Popular for high-level managers
- Common examples (EXCEL): PivotTable, PivotChart

Schedule vs Cost Monitoring

- Schedule estimates: Aggregate measures suspect
  - Remember that some activities much more important than others!
    - May want to track particular activities
  - Falling behind on non-critical activities may shift critical path
- Cost estimates: All sources of cost can lead to cost overruns
  - In general, impact of absolute cost overrun from one activity similar to other activities

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Performance Metrics

- Main categories of performance metrics:
  - scope
  - time
  - money
  - quality
  - productivity
  - safety
- Performance Metrics typically are defined in preparation for project monitoring before project control.
- Must facilitate the project control process as well as the reporting functions of project monitoring

Main Performance Metrics

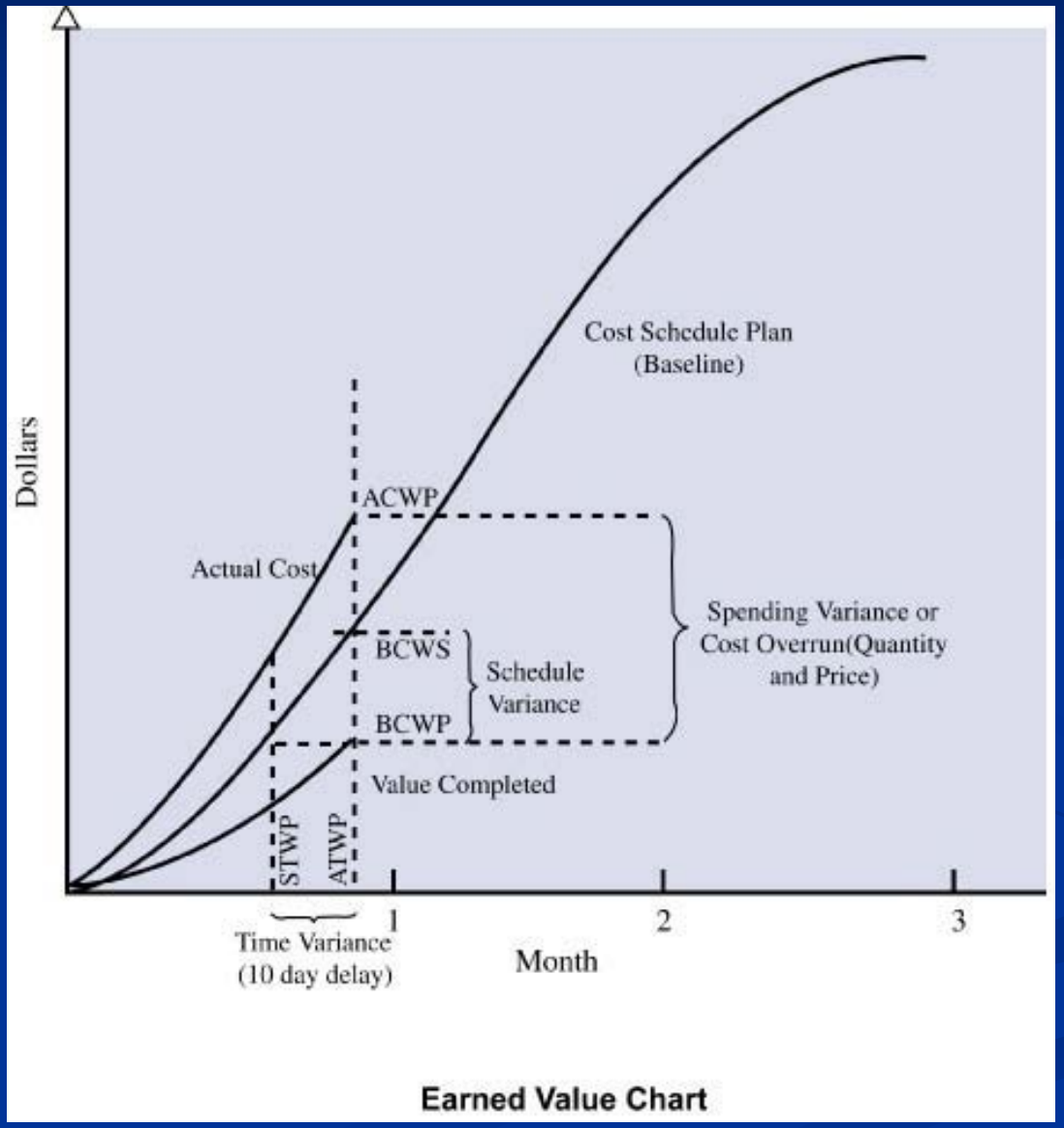
Categories	Performance measurements	Targets	Units of measurement
Scope	Amount of work accomplished	Amount of work to be accomplished	M, M^2, M^3, Tons, $
Time	Completion dates	Milestones, Deadline	Day, Week, Month
Money	Cost, Cash flow	Budget, Profit, Cash flow	$, Net Present Value (NPV)
Quality	Quality achieved (Appearance, Durability, Strength, Suitability)	Target quality level (Appearance, Durability, Strength, Suitability)	Number of defects, Value of defects, Number of change orders
Safety	Actual accidents and injuries, delays and economic damages occurred	Goaled accidents and injuries level	Person, $, Day, Week, Month
Productivity	Actual productivity	Planned productivity	Work unit/worker/time

Earned Value Approach - Definitions

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

- Budgeted Cost of Work Scheduled (BCWS, $): 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)

Earned Value Chart



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)

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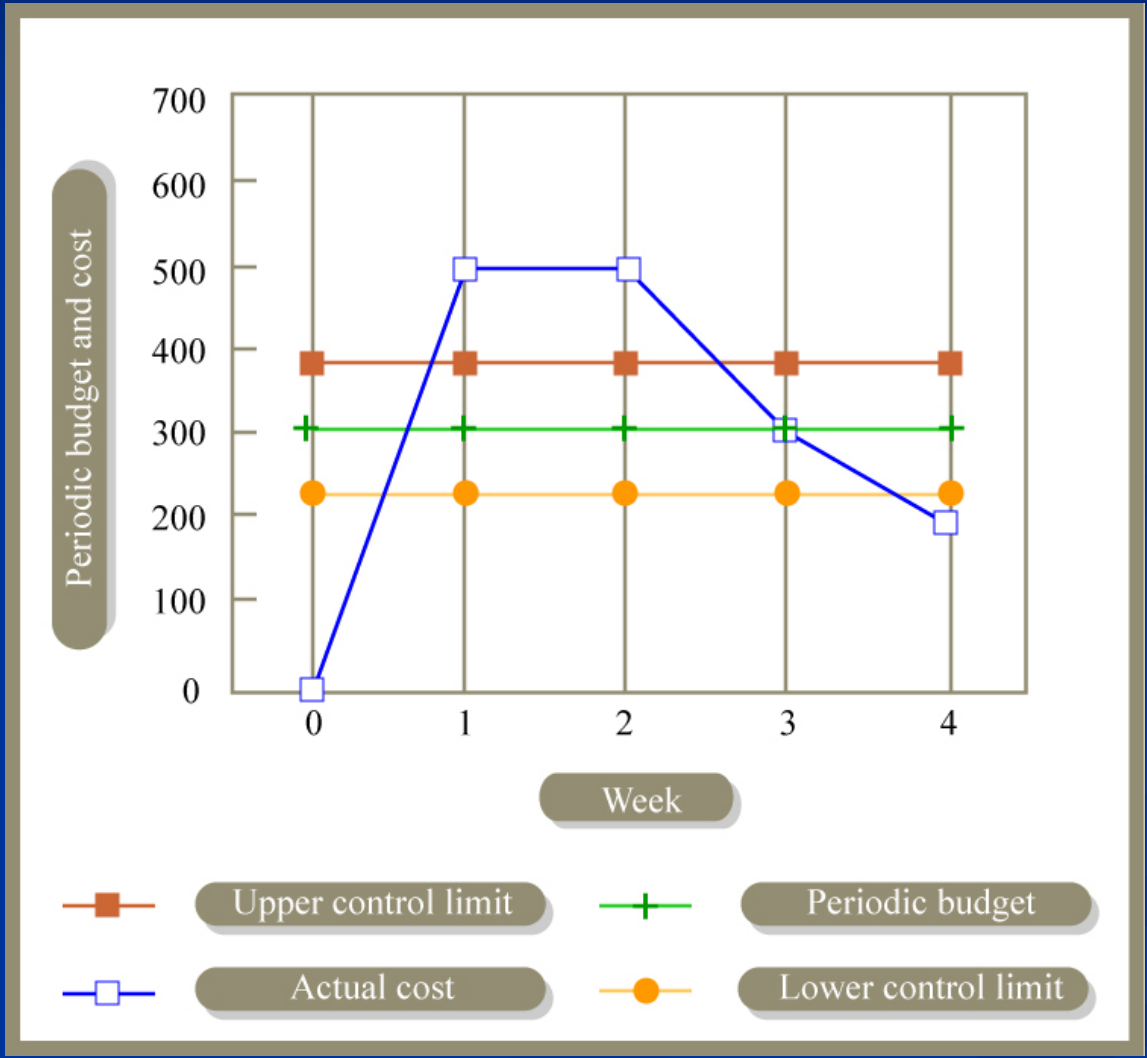
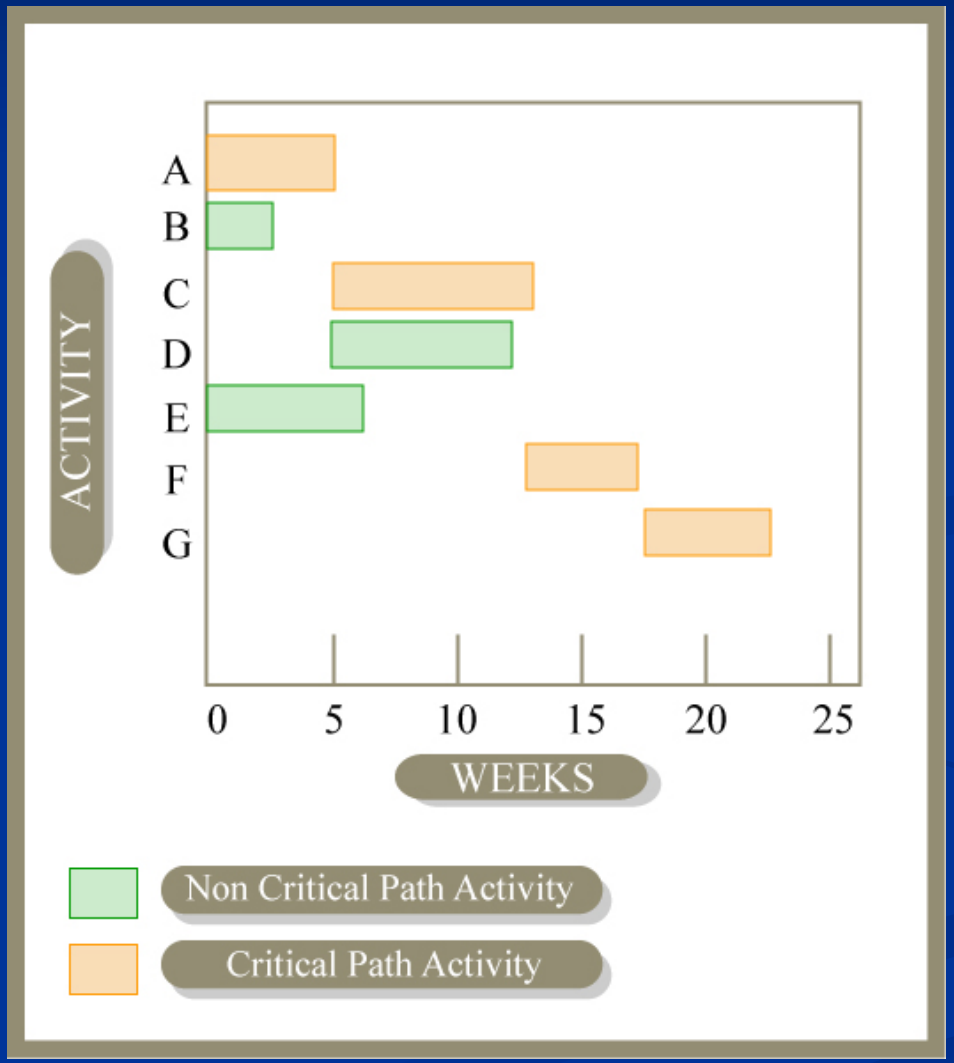
Resource Flow Variance

- *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)

Control Limits



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

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

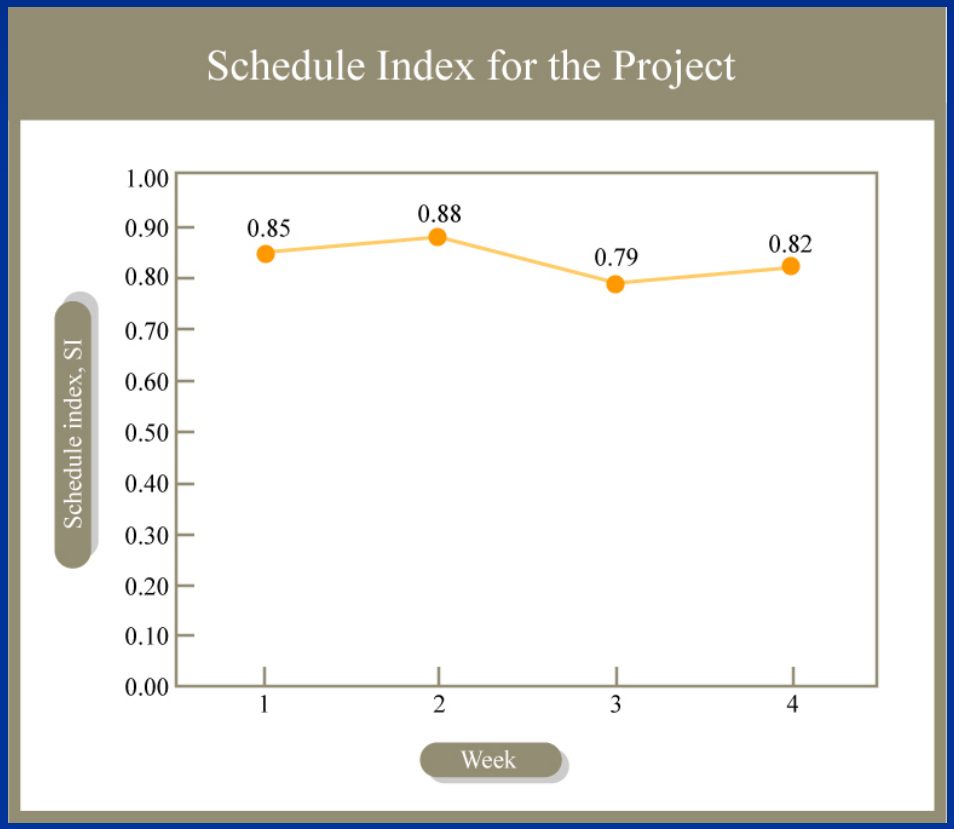
	Week 1			Week 2			Week 3			Week 4		
Activity	BCWS	BCWP	ACWP	BCWS	BCWP	ACWP	BCWS	BCWP	ACWP	BCWS	BCWP	ACWP
A	300	500	500	300	500	500	300	300	300	300	200	200
B	1,000	1,000	1,000	1,000	1,000	1,000	1,000	500	500	0	500	500
E	814	300	814	814	400	686	814	500	1,000	814	428	400
	2,114	1,800	2,314	2,114	1,900	2,186	2,114	1,300	1,800	1,114	1,128	1,100

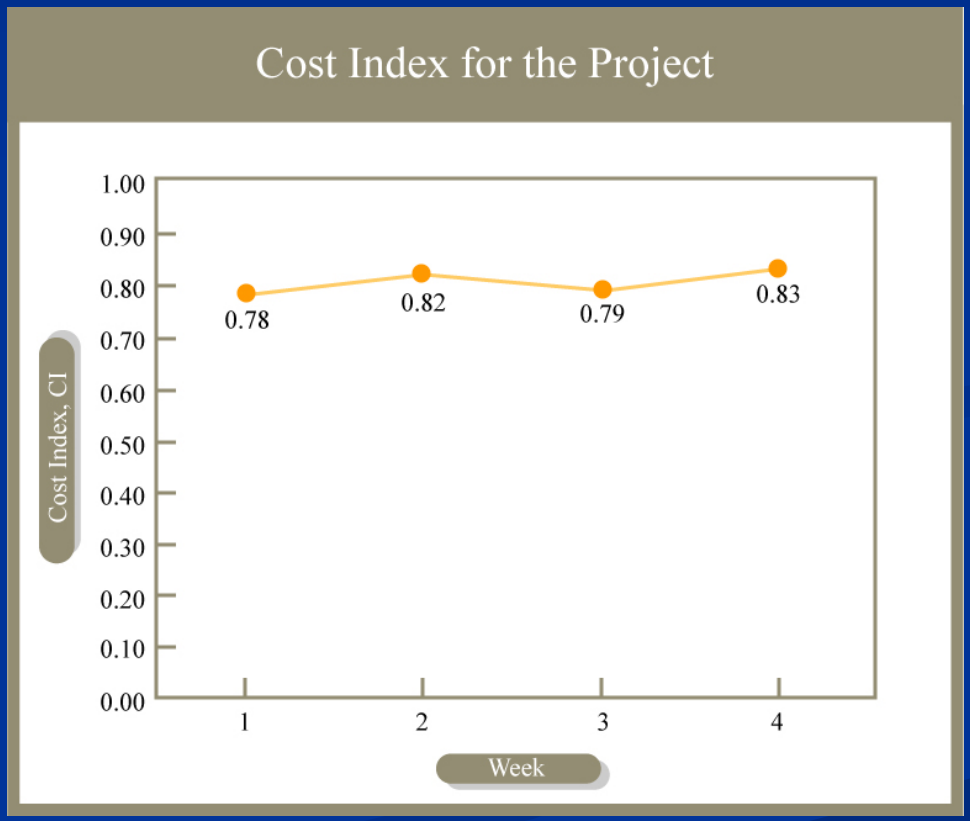
Example: Earned Value Analysis

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