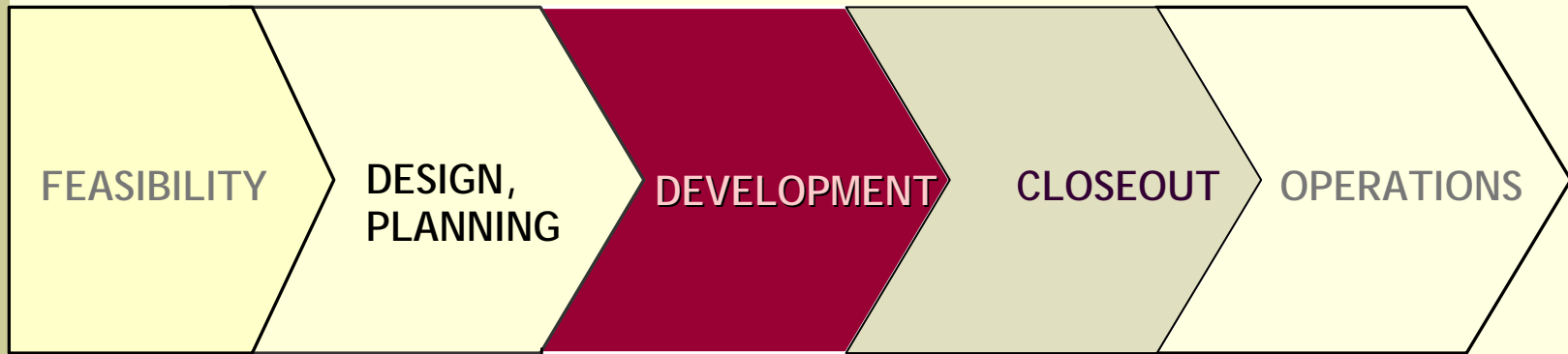


1.040/1.401/ESD.018  
Project Management  
Spring 2007

Lecture 17  
Cost and Schedule Monitoring

Sam Labi and Fred Moavenzadeh  
Department of Civil and Environmental Engineering  
Massachusetts Institute of Technology

# Recall: The 5 Phases of Project Management



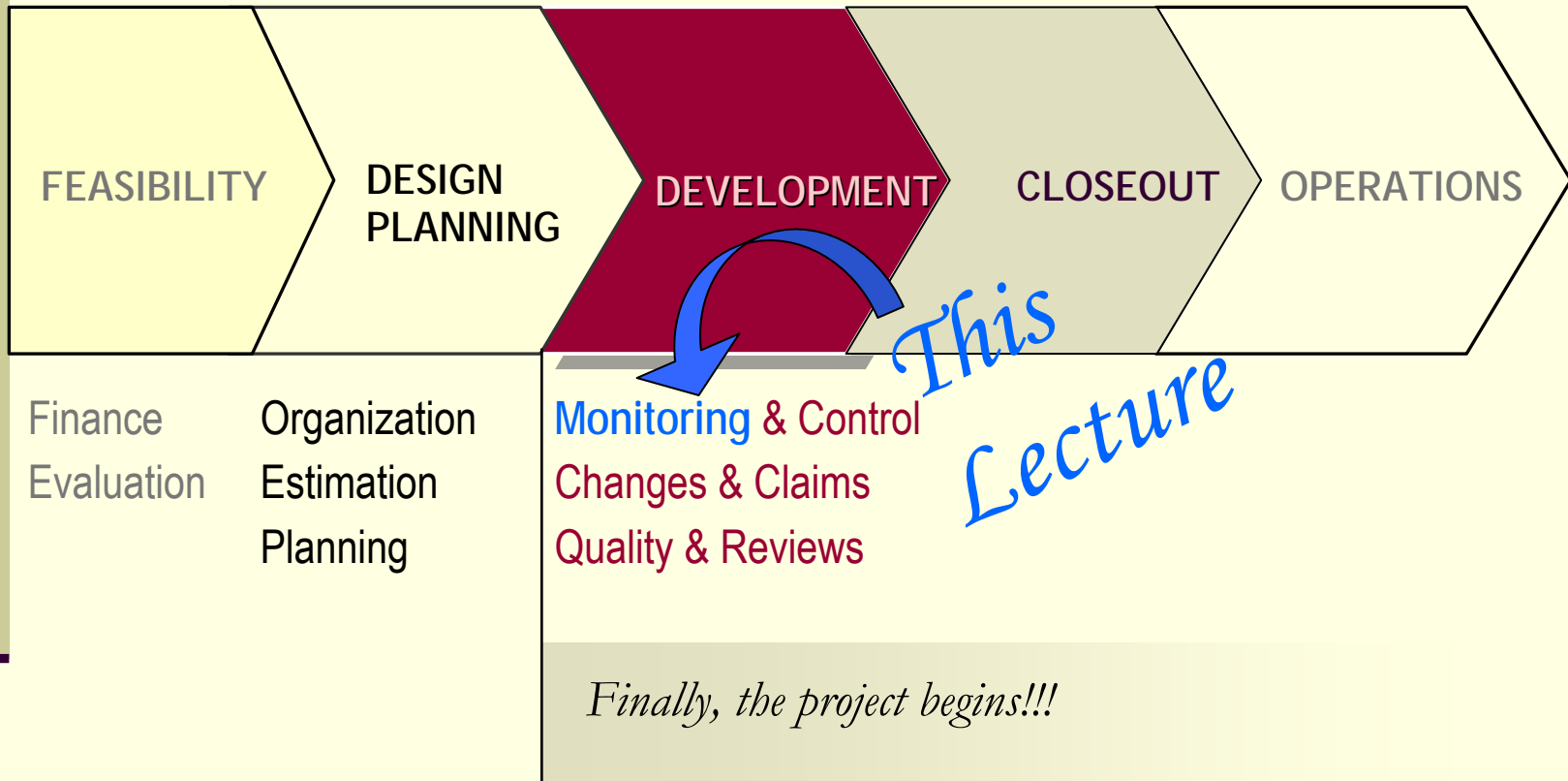
Finance  
Evaluation

Organization  
Estimation  
Planning

Monitoring & Control  
Changes & Claims  
Quality & Reviews

*Finally, the project begins!!!*

# Recall: The 5 Phases of Project Management



# Project Monitoring -- Outline

---

- Links to preceding and subsequent tasks

*How is project monitoring linked to project evaluation and planning?*

*What did we evaluate and plan that we also need to monitor?*

- Key components of project monitoring

*What is needed?*

- Measurement: basics of cost and schedule tracking

*How do we establish a “track”?*

- Performance Metrics

- Earned Value Analysis (EVA)

*What have we achieved so far?*

- Performance indices

*Are we on the right track? How do we know?*

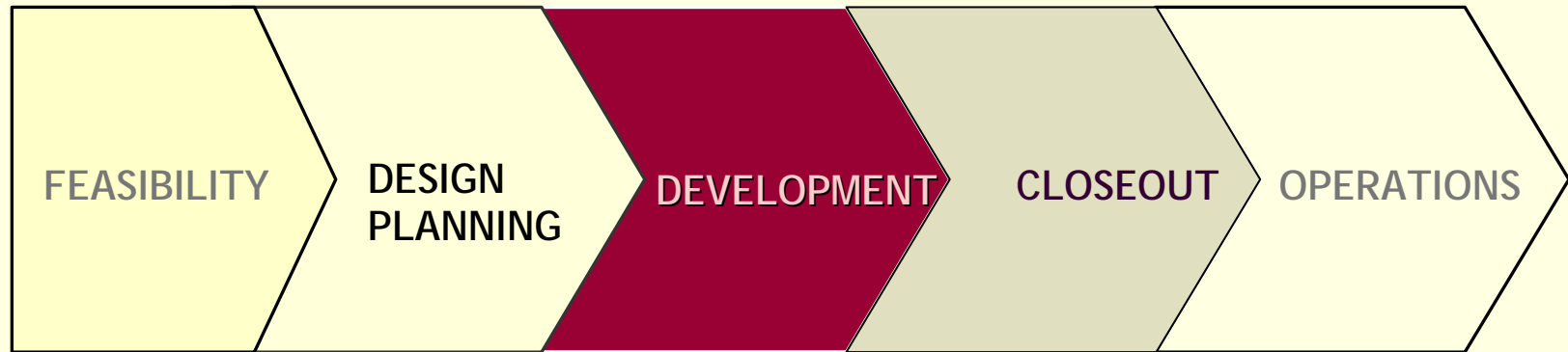
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# PART 1

## Links between Project Monitoring and its Preceding or Succeeding Phases

# 1. Links to Preceding and Subsequent Tasks

## 1. A Link to Project Evaluation and Finance



Finance	Organization	<b>Monitoring &amp; Control</b>
Evaluation	Estimation	Claims
	Planning	Quality reviews



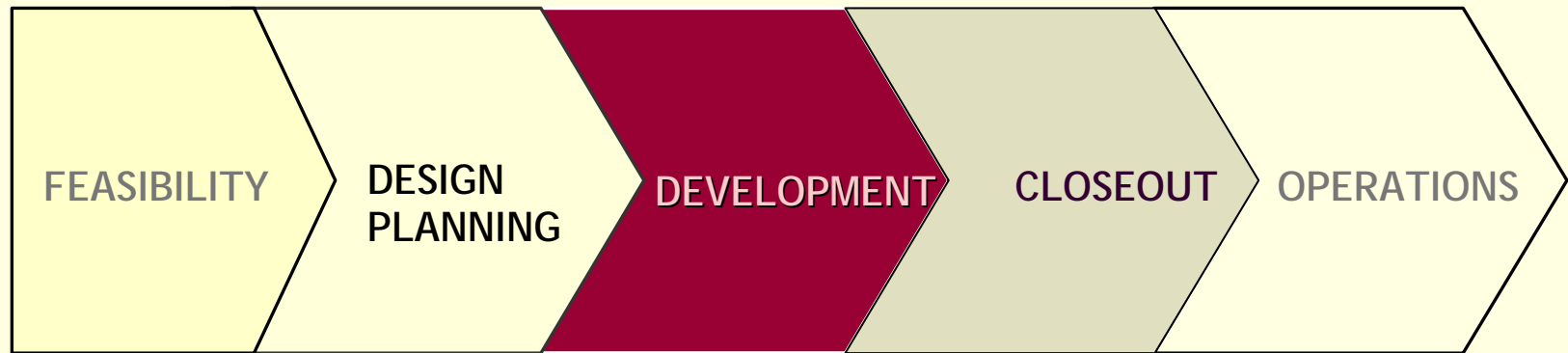
*Products:*

*Cash flow diagram indicating Project cash inflows and outflows and when they are expected to occur*

*NPV or B/C ratio each year of the analysis period*

# 1. Links to Preceding and Subsequent Tasks

## 1. A Link to Project Evaluation and Finance



Finance  
Evaluation

Organization  
Estimation  
Planning

**Monitoring & Control**  
Claims  
Reviews

*What is the actual cash flow for the project?*

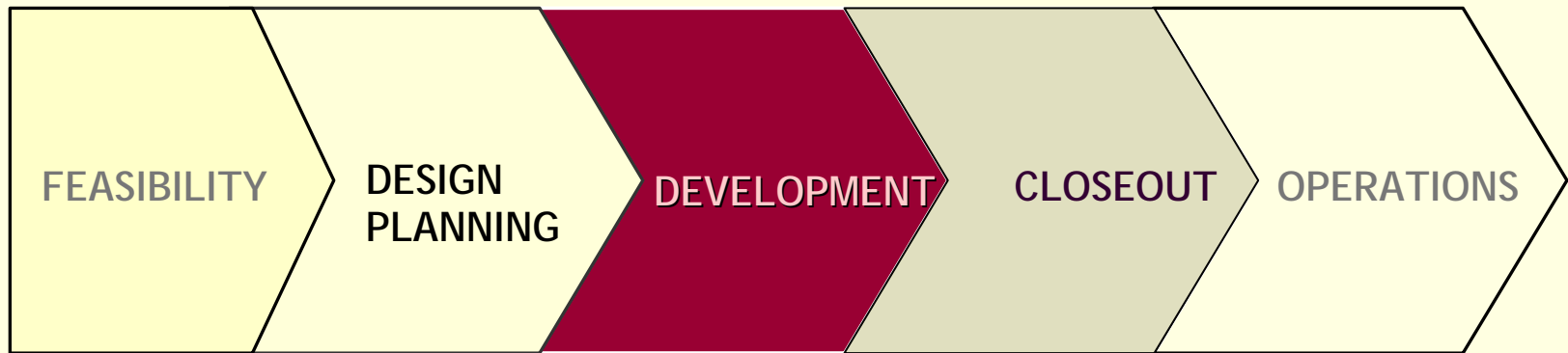
*Products:*

*Cash flow diagram indicating Project cash inflows and outflows and when they are expected to occur*

*NPV or B/C ratio each year of the analysis period*

# 1. Links to Preceding and Subsequent Tasks

## 1.B Link to Project Organization, Estimation, and Planning



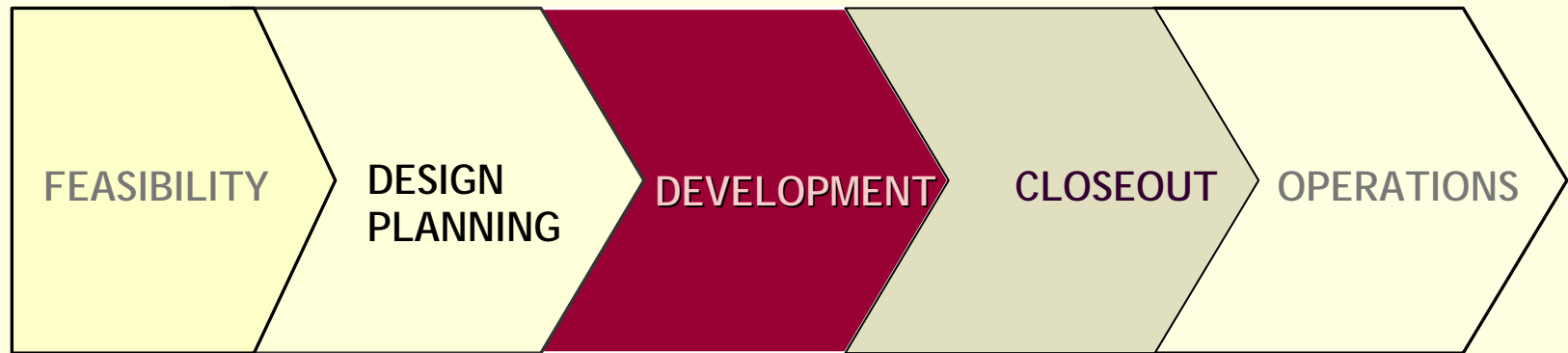
*What amounts of man-power, machinery-hours, materials, is the project actually using?*

- Products:**
- Time-based or Work-based Schedules for Utilization of Funds, Labor, Equipment, Materials*
  - Time- Schedule for each Activity or Task*
  - Project Costs for each Activity*
  - Expected quality levels for each activity*



# 1. Links to Preceding and Subsequent Tasks

## 1.B Link to Project Organization, Estimation, and Planning



Finance  
Evaluation

Organization  
Estimation  
Planning

Monitoring & Control  
Quality Reviews

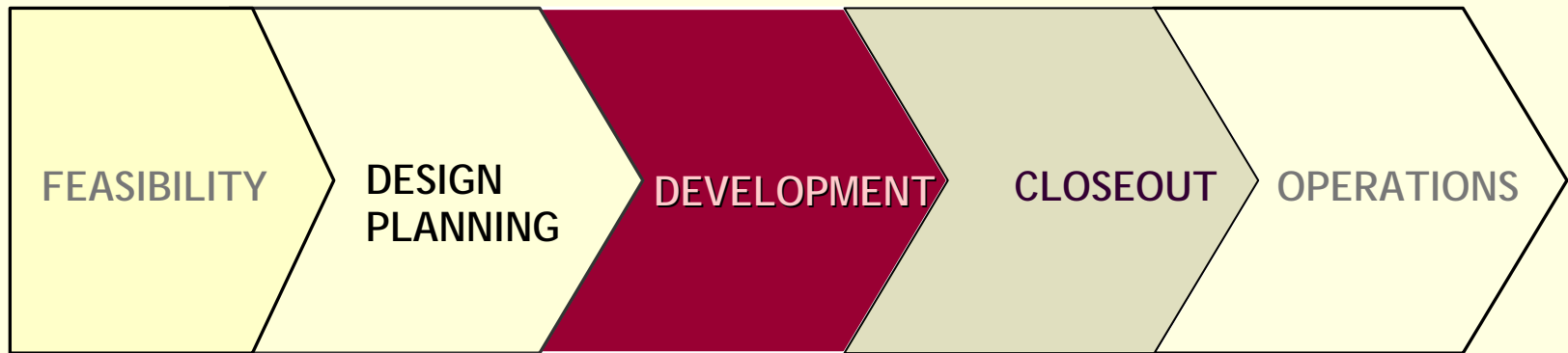
*What are the actual start-times, end times, durations of each activity?*

**Products:**

- Time-based or Work-based Schedules for Utilization of Funds, Labor, Equipment, Materials*
- Time- Schedule for each Activity or Task*
- Project Costs for each Activity*
- Expected quality levels for each activity*

# 1. Links to Preceding and Subsequent Tasks

## 1.B Link to Project Organization, Estimation, and Planning



Finance  
Evaluation

Organization  
Estimation  
Planning

Monitoring & Control  
Quality Reviews  
Claims

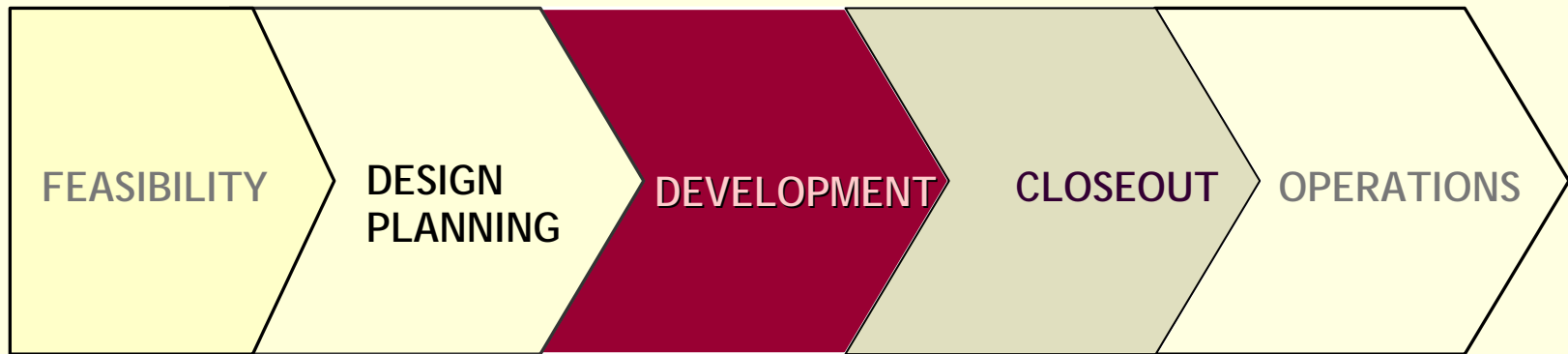
*How much are we actually spending on each project activity or task?*

**Products:**

- Time-based or Work-based Schedules for Utilization of Funds, Labor, Equipment, Materials*
- Time- Schedule for each Activity or Task*
- Project Costs for each Activity*
- Expected quality levels for each activity*

# 1. Links to Preceding and Subsequent Tasks

## 1.B Link to Project Organization, Estimation, and Planning



Finance  
Evaluation

Organization  
Estimation  
Planning

Monitoring & Control  
Claims  
Reviews

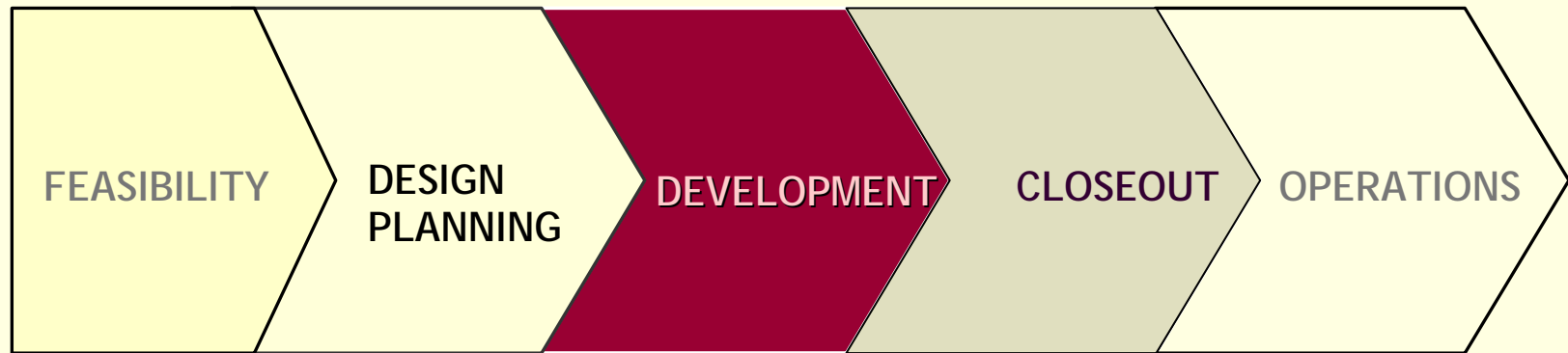
*What quality levels are we actually achieving?*

**Products:**

- Time-based or Work-based Schedules for Utilization of Funds, Labor, Equipment, Materials*
- Time- Schedule for each Activity or Task*
- Project Costs for each Activity*
- Expected quality levels for each activity*

# 1. Links to Preceding and Subsequent Tasks

## 1. C Link to Project Control



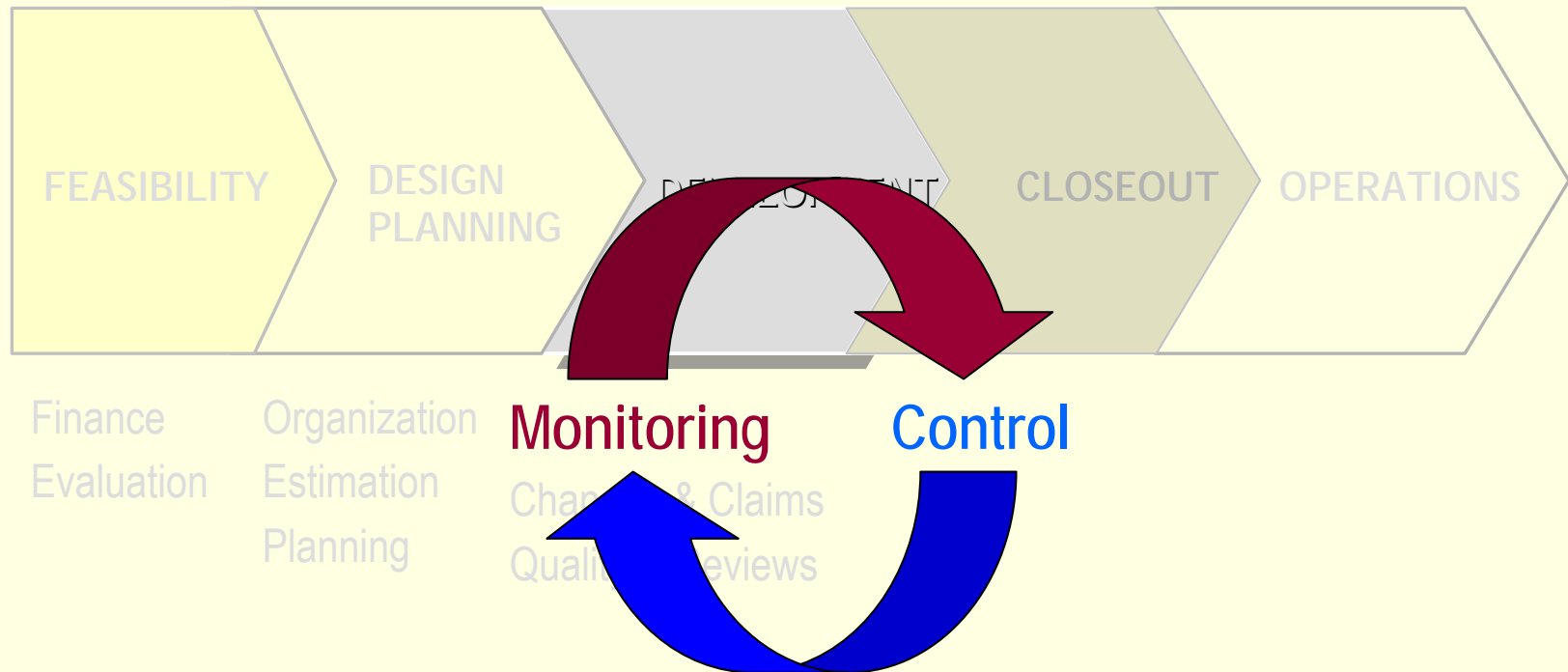
Finance	Organization	<b>Monitoring &amp; Control</b>
Evaluation	Estimation	Control & Rev
	Planning	



*What do we learn from Monitoring*  
*How can we use these lessons to improve the project (\$, time, quality)*

# 1. Links to Preceding and Subsequent Tasks

## 1. C Link to Project Control



*MONITORING AND CONTROL: A FEEDBACK PROCESS*

# 1. Links to Preceding and Subsequent Tasks

## 1. C Link to Project Control

---

- Goal of Project Monitoring: To detect, at any time of the project, the following:

- Deviations from Budget
- Lagging Schedule
- Poor Quality

Key questions in monitoring:

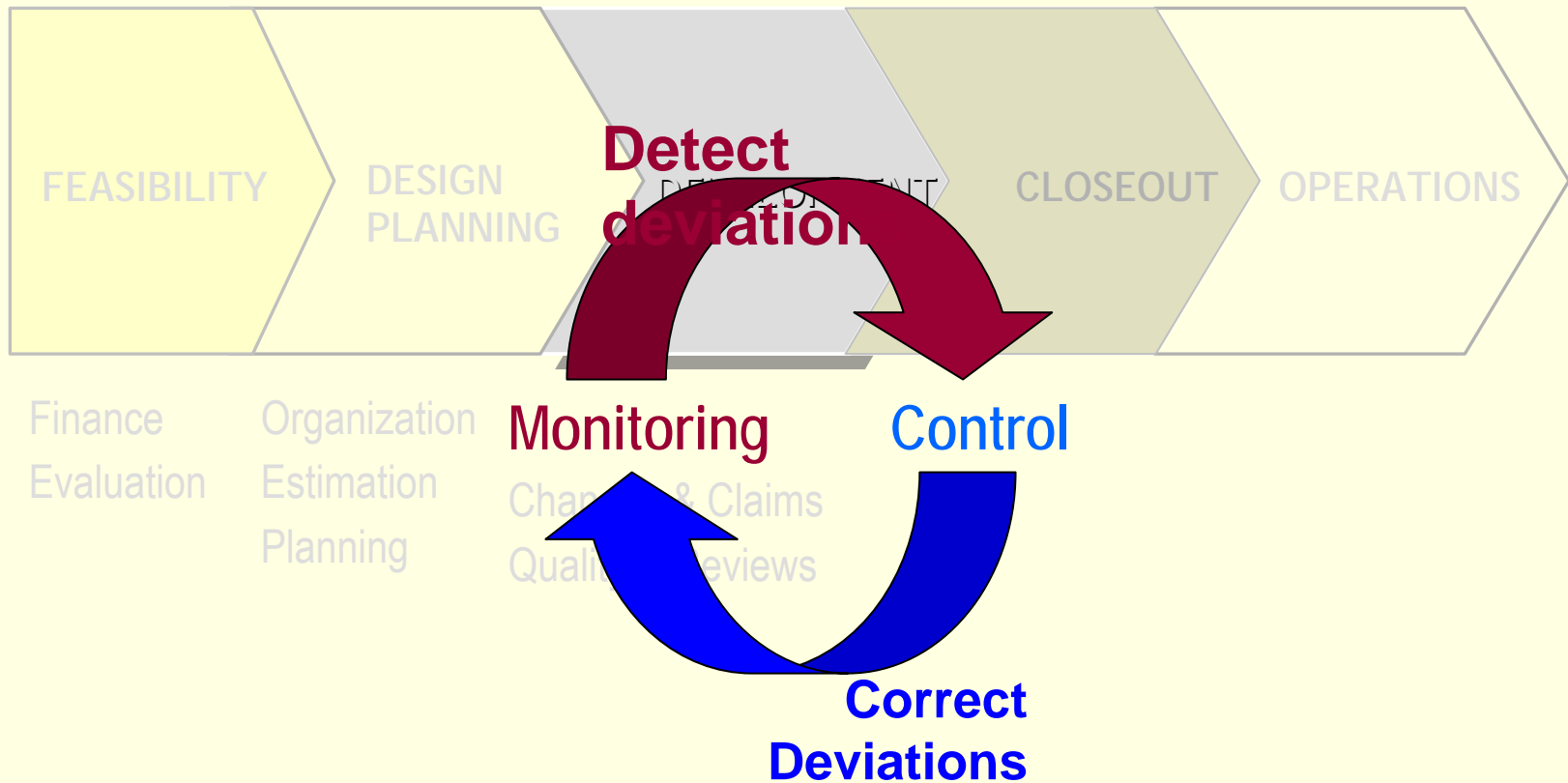
What/How should we measure?

Will we know it soon enough?

- Goal of Project Control: To correct, at any time of the project, the deviations from budget, schedule, and quality.
  - Bring project performance (budget, time, quality) back in line with plans
  - Sometimes, revise plans to bring them in line with performance!!!

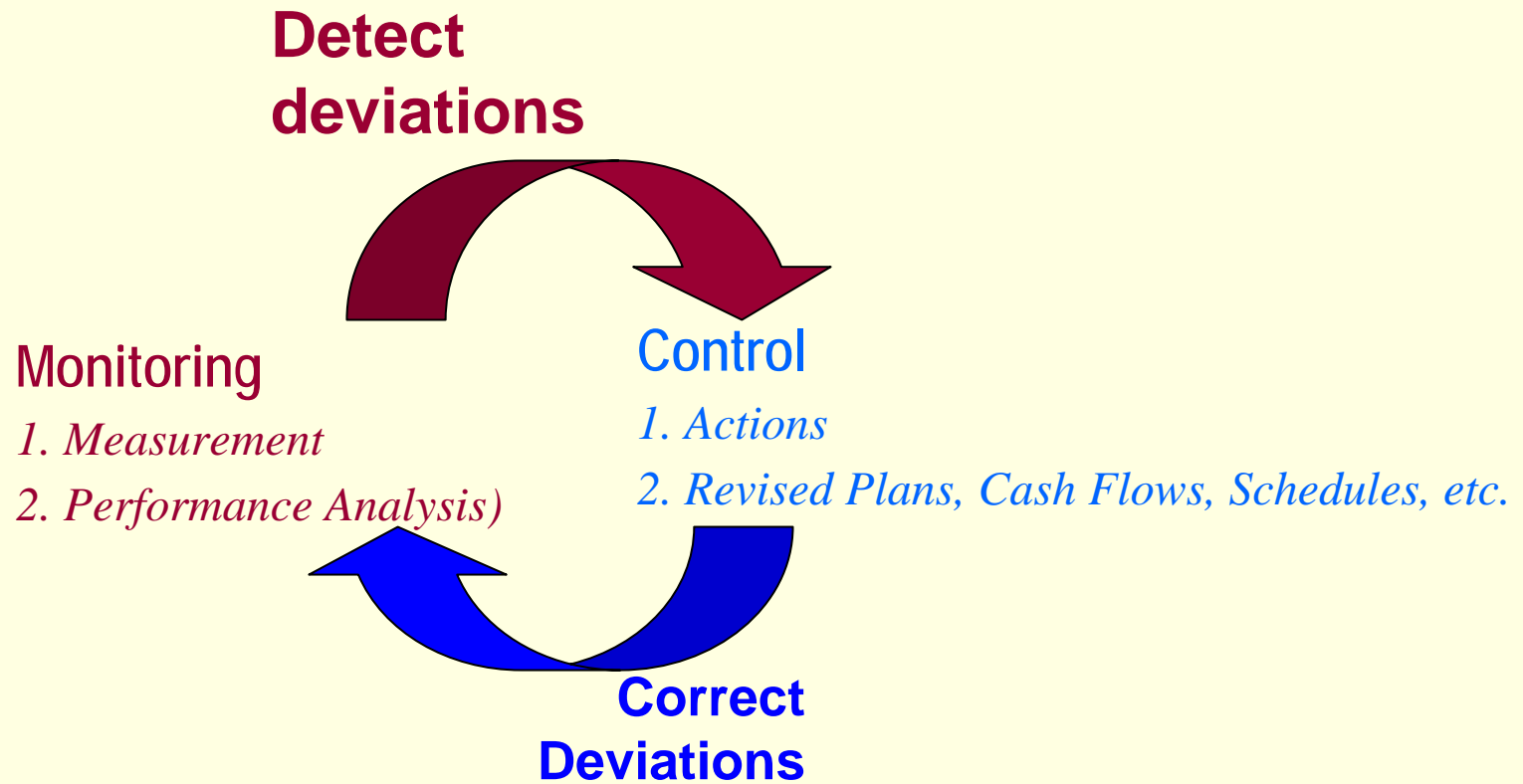
# 1. Links to Preceding and Subsequent Tasks

## 1. C Link to Project Control



# Monitoring & Control – The Feedback Process

---





# Critical Role of a Feedback System

---

*Is the Feedback system necessary?*

*Why not just carry out “totally static planning” or “forward ever”?*

- In real world, planning is never perfectly deterministic
- Nothing always goes perfectly according to the original plan
- Why/How?
  - Physical: Inclement weather, unforeseen geotechnical conditions, unforeseen utility location problems, etc.
  - Early or late delivery of procured items
  - Changes in Owner requirements
  - Changes in worker and equipment productivity
  - Community opposition to project conditions (noise, dust, etc.)
  - Design and planning errors (inappropriate assumptions)

# Definition of Project Monitoring

---

Procedures for  
collecting data about  
project performance (achieved or forecasted)

Again, note that:

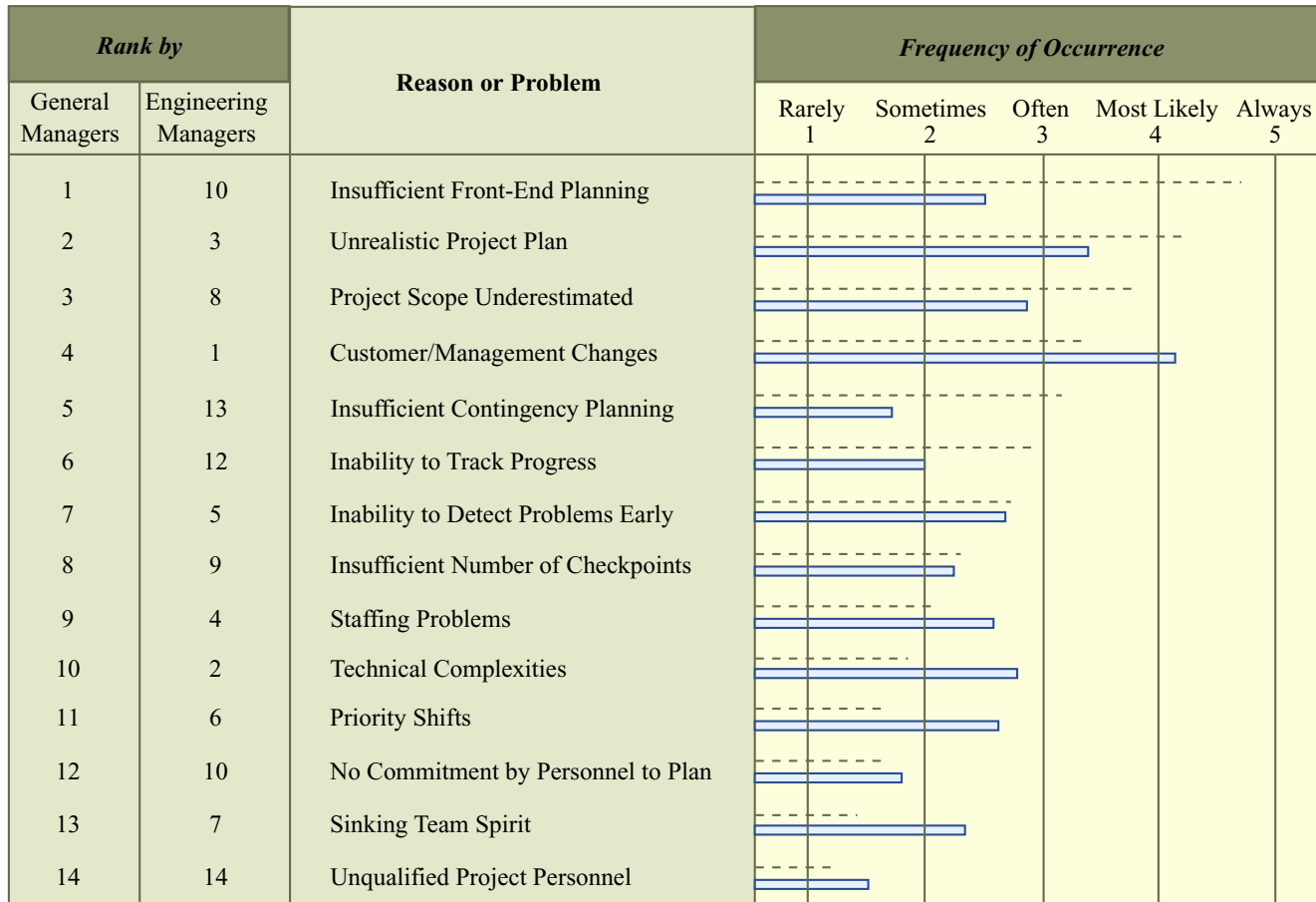
1. Performance could be in terms of time, money, or quality
2. Forecast performance = “program”  
Achieved performance = “progress”
3. Technology helps greatly in project monitoring (recall lecture by Dr. Slaughter)

# Avoiding Deviations in Project Cost, Time, and Quality – Common Challenges Faced by Project Managers

---

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%

# Reasons Often Cited for Cost and Schedule Deviations



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

Figure by MIT OCW.



PART 2

Key Components  
of  
Effective Monitoring



## *What do we need in order to monitor a project properly?*

---

- A Mechanism for Progress Measurement
- Representative Performance Metrics (established at planning phase)
- Cost & Schedule Milestones should be well-defined
- Reporting Schedule (perhaps of variable  $\Delta t$ '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

# For effective monitoring, these should be the characteristics of your budget:

---

## Budgets

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

Figure by MIT OCW.

# For effective monitoring, these should be the characteristics of your activities:

---

## Activities

- ★ Activities are part of a clear and systematic cost model (e.g., the WBS).
- ★ They are clearly defined in terms of the work to be performed, results, timing, and individual responsibilities.
- ★ Activities are agreed on by the individual responsible regarding the work, timing and budget.
- ★ There are measurable milestones and deliverables.
- ★ Activities are associated with a singular controlling authority, responsible 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.

Figure by MIT OCW.





## PART 3

### Measurement of Project Progress: The basics of cost and schedule tracking

# Measurement of Project Progress

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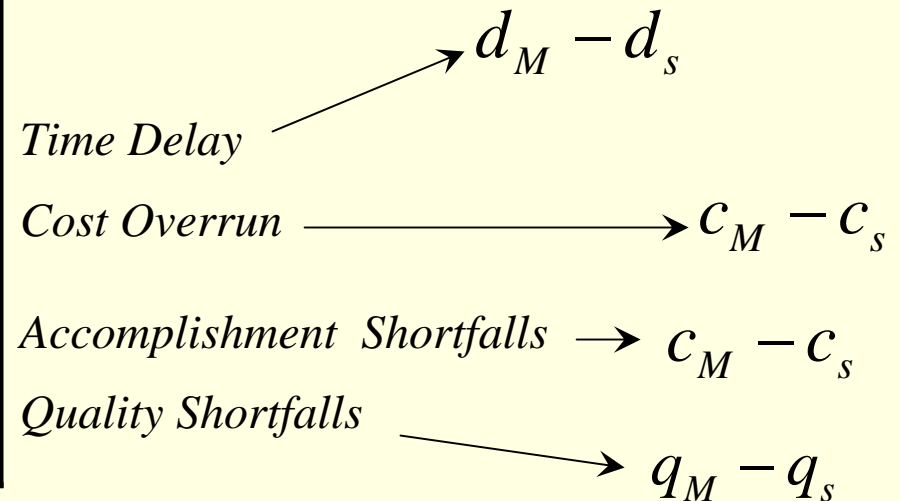
*Mr. X: "This project is going well because it is in its 14<sup>th</sup> month and has spent \$4.5 million."*

- Some traditional measures of project "progress" are based on only the actual resources consumed
  - Time spent
  - Money spent (Actual Cost)
  
- What is the problem with this?

# Measurement of Project Progress

Progress can be measured at any time of the project

	Scheduled (Plan)	Monitored (Progress)
Time <sup>1</sup>	$d_S$	$d_M$
Costs	$c_S$	$c_M$
Work Done <sup>2</sup>	$w_S$	$w_M$
Quality <sup>3</sup>	$q_S$	$q_M$



Here, Time Performance is for specific activities only, not for entire project, unless the entire project has been completed.

Here Work Performance can be expressed in terms of input (man-hours, equipment-hours, material quantities used, etc.) or output (area or volume installed/constructed, etc.), or a combination of these.

Quality Performance can be expressed in terms of the number or laboratory tests and site measurements that indicated project compliance to materials and workmanship specification, respectively.

# Measurement of Project Progress

Progress can be measured at any time of the project

	Scheduled (Plan)	Monitored (Progress)
Time	$d_S$	$d_M$
Costs	$c_S$	$c_M$
Work Done	$w_S$	$w_M$
Quality	$q_S$	$q_M$

$Time\ Delay \rightarrow 100 \times \left( \frac{d_M - d_S}{d_S} \right)$   
 $Cost\ Overrun \rightarrow 100 \times \left( \frac{c_M - c_S}{c_S} \right)$   
 $Accomplishment\ Shortfalls \rightarrow 100 \times \left( \frac{w_M - w_S}{w_S} \right)$   
 $Quality\ Shortfalls \rightarrow 100 \times \left( \frac{q_M - q_S}{q_S} \right)$

# Measurement of Project Progress - Example

	Scheduled (Plan)	Monitored (Progress)
Time	<i>18 months</i>	<i>20 months</i>
Costs	<i>\$1.1 million</i>	<i>\$1.24 million</i>
Quality	<i>All of the 1,345 tests</i>	<i>Only 1,329 of the tests</i>

*Time Delay*

$$100 \times \left( \frac{20 - 18}{18} \right) = 2.22\%$$

*Cost Overrun*

$$100 \times \left( \frac{1.24 - 1.1}{1.1} \right) = 12.73\%$$

*Quality Shortfalls*

$$100 \times \left( \frac{1329 - 1345}{1345} \right) = 1.19\%$$

# Some Terminology

---

- Deviation in cost/expenditure
  - Cost overrun or excess expenditure
  - Cost underrun
  
- Deviation in time
  - Time Delay or Schedule Slip
  
- Deviation in quality – Workmanship Quality Lapses
  - Workmanship/material/product Quality Lapses
  - Workmanship/material/product Quality Compliance

# How do we measure $a_M$ ?

	Scheduled (Plan)	Monitored (Progress)
Time	$d_S$	$d_M$
Costs	$c_S$	$c_M$
Work Done	$a_S$	$a_M$
Quality	$q_S$	$q_M$

## Method 1: Using inputs

Amount of man-hours, equipment hours, raw materials used.

*What is the disadvantage of this method?*

## Method 2: Amount of work actually accomplished

E.g., nr. of columns placed, panel mounted, etc.

linear ft. of tracks laid, rebar or piping installed, etc.

area of landscaping, drywall placed, etc.

volume/weight of earth excavated, concrete cast, asphalt laid, etc.

# How do we collect the data for measuring $a_M$ ?

---

- Foremen/superintendents note work inputs and accomplishments on timesheets (or PDAs)
  - Identify appropriate cost categories associated to each work activity
  - Enter quantities in Quantities Book
  - Enter worked hours in Timesheets
    - Hours worked can be obtained from project's payroll clerk



# *How frequently do we monitor?*

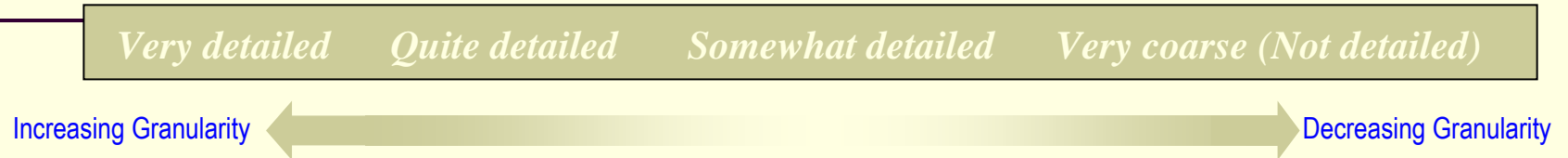


*Hourly? Daily? Weekly? Bi-weekly? Monthly? Quarterly? Yearly? etc.*

## **Monitoring Frequency Depends On**

- Size/Duration of the project
- Practicality
- What performance measure are we monitoring? Its importance
- What detail of performance is needed? (Granularity)
- Financial cost of what is being monitored
- Criticality of the activity to be monitored
- Familiarity of the monitoring procedure
- Cost of monitoring and Resources available for monitoring

# How detailed should we be?



- Advantages of high granularity
  - Preserves option of finer investigation
  - Can allow for quicker ...
    - ... response to deviations
    - ... assessment of the efficacy of project control strategies helping
  
- Advantages of low granularity
  - Fewer staff needed for monitoring
  - Faster recording (less time needed for monitoring)

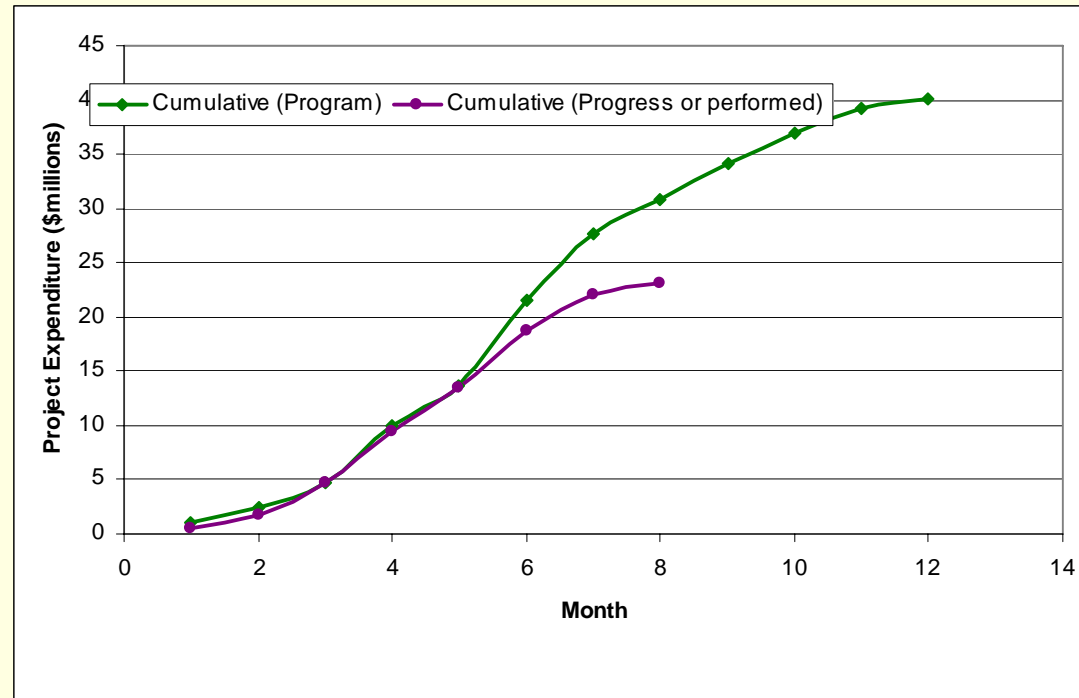
# How do we measure $c_M$ ?

	Scheduled (Plan)	Monitored (Progress)
Time	$d_S$	$d_M$
Costs	$c_S$	$c_M$
Work Done	$a_S$	$a_M$
Quality	$q_S$	$q_M$

## Basis for cost monitoring: Cost Breakdown Structure (CBS)

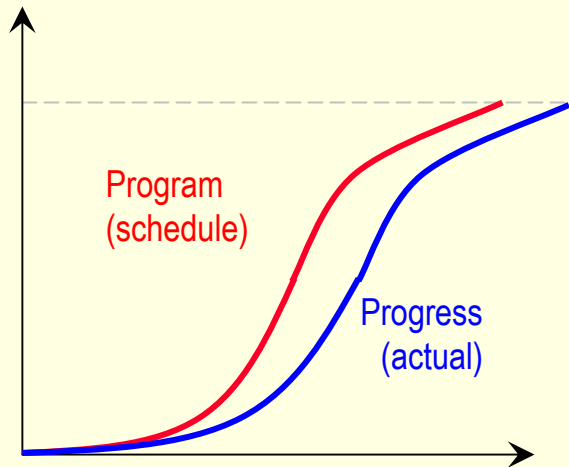
- Canonical way of monitoring cash flows (costs) of the project
- Different accounts used for different types of expenditures
- Permits monitoring of project expenditure for each activity (work item)
- Often consistent with work-based schedules.

# Simplified Examples of Project Progress Charts

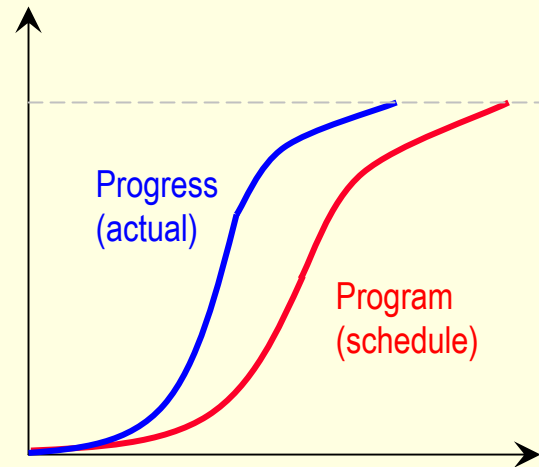


# Are simple program and progress charts enough to monitor performance?

Consider a set of work-based program and progress charts  
(example, amount of concrete (m<sup>3</sup>) cast on site)



Seems poor



Seems great

*EVA helps address  
this issue!*

But:

Seemingly good progress could be ...  
... because lots of unscheduled work has been done  
... because lots of low-weight work has been done  
... thus misleading

# Earned Value Analysis (EVA) - Definitions

---

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

- **BCWS**

- Budgeted Cost of Work Scheduled or programmed (\$): the value of work scheduled to be accomplished in a given period of time

- **ACWP**

- Actual Cost of Work Performed (\$): the costs actually incurred in accomplishing the work performed within the control time

- **BCWP**

- Budgeted Cost of Work Performed (\$): the monetary value of the work actually performed within the control time (= **Earned Value**).

# A clearer picture

*Used for plotting the  
Program S-curve*

	Work Schedule (WS)	Work Performed (WP)
Budgeted Cost (BC)	BCWS	BCWP
Actual Cost (AC)	<del>ACWS</del>	ACWP

*Used for plotting  
the EVA S-curve*

*Used for plotting the  
Progress S-curve*

# Therefore ...

	Work Schedule (WS)	Work Performed (WP)
Budgeted Cost (BC)	BCWS	BCWP
Actual Cost (AC)		ACWP

- At any time of the project, we can determine the following:
  - Budgeted value of a scheduled work item,  $BV = BC * WS$
  - Actual value of a performed work item =  $AC * WP$
  - Budgeted value of a performed work item =  $BC * WP$



# Example

	Work Schedule (WS)	Work Performed (WP)
Budgeted Cost (BC)	BCWS	BCWP
Actual Cost (AC)		ACWP

At any time of the project, we can determine the following:

- Budgeted value of a scheduled work item,  $BV = BC * WS$
- Actual value of a performed work item =  $AC * WP$
- Budgeted value of a performed work item =  $BC * WP$

WBS	WS	BV BCWS	WP	AV ACWP	EV BCWP
<b>Structures</b>	<b>60%</b>	<b>660,000</b>	<b>56%</b>	<b>700,000</b>	<b>621,297</b>
Footings	13%	148,200	14%	162,209	154,050
Procurement	100%	106,400	104%	118,500	110,600
Shipping	100%	15,200	104%	16,059	15,800
Construction	100%	26,600	104%	27,650	27,650
<b>Columns</b>	<b>47%</b>	<b>511,800</b>	<b>42%</b>	<b>537,791</b>	<b>467,247</b>
Procurement	65%	400,400	49%	345,600	302,400
Shipping	45%	32,310	49%	43,200	35,247
Construction	30%	79,090	49%	148,991	129,600

---

# PART 4

## Performance Metrics

1. Performance metrics based on Earned Value Analysis (EVA)
2. Other performance indices

# Project Progress Performance on basis of EVA – *Some useful metrics*

---

- Resource Flow Variance (RV)
- Resource Flow Index (RI)
- Cost Variance (CV)
- Cost Index (CI)
- Schedule Variance (SV)
- Schedule Index (SI)
- Time Variance (TV)

# Resource Flow Variance (RV)

**Definition:** A progress performance metric that ... compares how much we expect to spend during a given time-frame with what we actually spent (regardless of how much work got done!)

**Computation:**  $RV_t = BCWS_t - ACWP_t$

**Interpretation:** If  $RV_t$  is +ve, we are experiencing underrun  
If  $RV_t$  is -ve, we are experiencing overrun  
If  $RV_t$  is 0 or close, we are on target

	Work Schedule (WS)	Work Performed (WP)
Budgeted Cost (BC)	BCWS	BCWP
Actual Cost (AC)		ACWP

# Resource Flow Index (RI)

---

Definition: Same as that for RV. But is a ratio rather than a difference between the two values.

Computation:  $RI_t = BCWS_t / ACWP_t$

Interpretation: If  $RI_t > 1$ , we are experiencing underrun  
If  $RI_t < 1$ , we are experiencing overrun  
If  $RI_t = 1$ , we are on target

	Work Schedule (WS)	Work Performed (WP)
Budgeted Cost (BC)	BCWS	BCWP
Actual Cost (AC)		ACWP

# Cost Variance (CV)

**Definition:** A progress performance metric that ... compares the budgeted value of work done vs. the actual value of work done.

**Computation:**  $CV_t = BCWP_t - ACWP_t$   
 $= \text{Earned Value (EV}_t) - \text{Actual Value (AV}_t)$

**Interpretation:** If  $CV_t$  is +ve, underrun or gain of value  
If  $CV_t$  is -ve, overrun, or loss of value  
If  $CV_t$  is 0 or close, we are on budget

	Work Schedule (WS)	Work Performed (WP)
Budgeted Cost (BC)	BCWS	BCWP
Actual Cost (AC)		ACWP

# Cost Index (CI)

Definition: Same as that for Cost Variance,  
but involves a ratio instead of a difference.

Computation:  $CI_t = BCWP_t / ACWP_t$   
= Earned value ( $EV_t$ )/Actual Value ( $AV_t$ )

Interpretation: If  $CI_t > 1$ , underrun or gain of value  
If  $CI_t < 1$ , overrun, or loss of value  
If  $CI_t = 1$ , we are right on budget

	Work Schedule (WS)	Work Performed (WP)
Budgeted Cost (BC)	BCWS	BCWP
Actual Cost (AC)		ACWP

# Schedule Variance (SV)

**Definition:** A progress performance metric that ...  
... compares the budgeted value of work done vs. the earned value of work done.

**Computation:**  $SV_t = BCWP_t - BCWS_t$   
 $= \text{Earned Value (EV}_t) - \text{Budgeted Value (BV}_t)$

**Interpretation:** If  $SV_t$  is +ve, project is ahead or has gained time  
If  $SV_t$  is -ve, project is behind or has lost time  
If  $SV_t$  is 0 or close, project is on schedule

	Work Schedule (WS)	Work Performed (WP)
Budgeted Cost (BC)	BCWS	BCWP
Actual Cost (AC)		ACWP



# Schedule Index (SI)

Definition: Same as that for Schedule Variance, but involves a ratio instead of a difference.

Computation:  $SI_t = BCWP_t / BCWS_t$   
 $= \text{Earned Value (EV}_t\text{)}/\text{Budgeted Value (BV}_t\text{)}$

Interpretation: If  $SI_t > 1$ , project is ahead or has gained time  
If  $SI_t < 1$ , project is behind or has lost time  
If  $SI_t = 1$ , project is on schedule

	Work Schedule (WS)	Work Performed (WP)
Budgeted Cost (BC)	BCWS	BCWP
Actual Cost (AC)		ACWP

# Time Variance or Duration Variance (TV)

---

**Definition:** A progress performance metric that ...

... assesses whether the project is spending more time (or less time) for an activity

... compares the scheduled duration (ST) of work performed vs. the actual duration (AT) of work performed.

**Computation:**  $TV_t = STWP_t - ATWS_t$

**Interpretation:** If  $TV_t$  is +ve, project is ahead or has gained time

If  $TV_t$  is -ve, project is behind or has lost time

If  $TV_t$  is 0 or close, project is on schedule

# Time Index (TI)

---

**Definition:** Same as that for Time Variance but involves a ratio rather than a difference.

**Computation:**  $TI_t = STWP_t / ATWS_t$

**Interpretation:** If  $TI_t$  is +ve, project is ahead or has gained time  
If  $TI_t$  is -ve, project is behind or has lost time  
If  $TI_t$  is 0 or close, project is on schedule

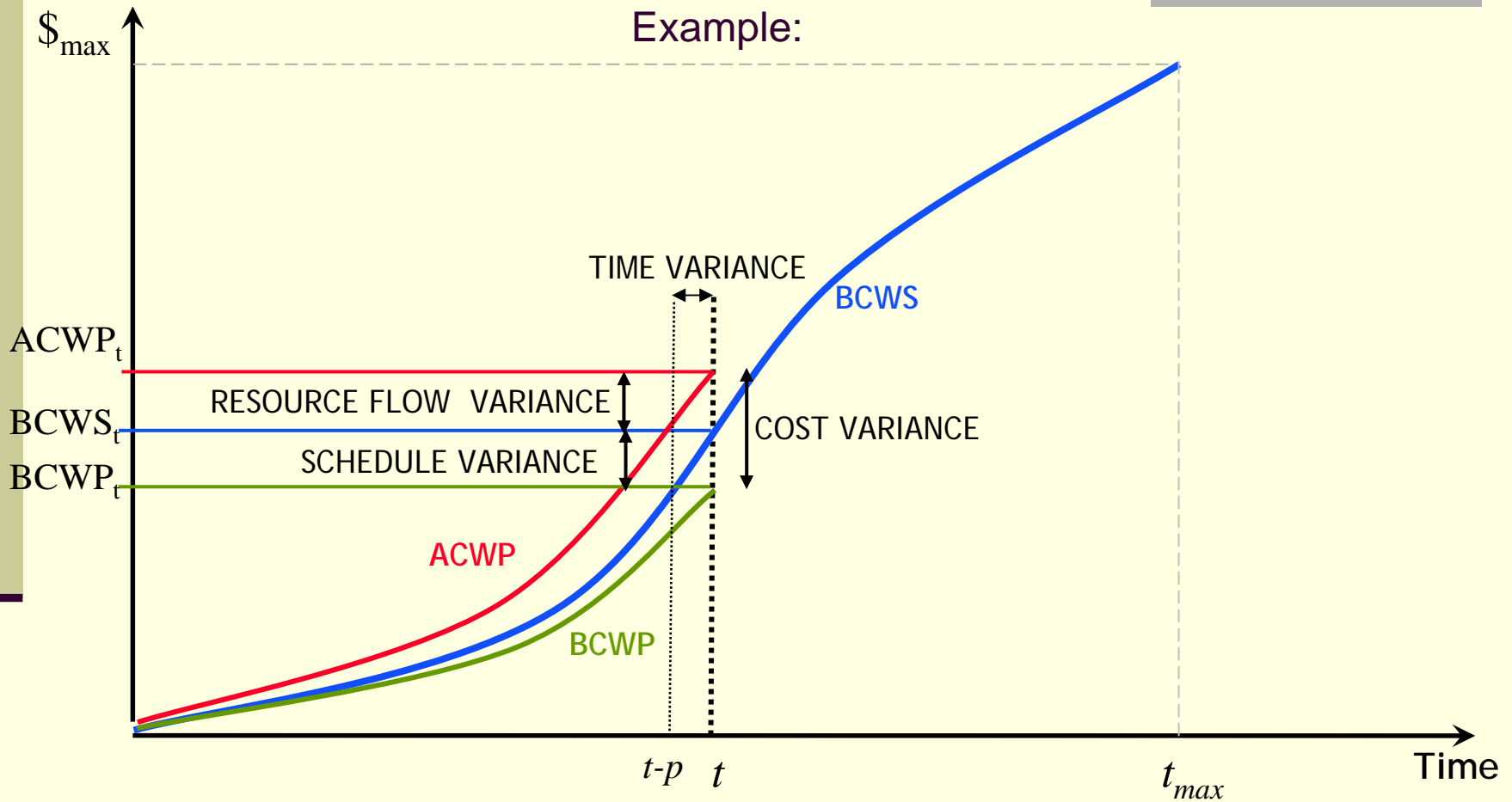
# Project Progress Performance on basis of EVA – *Useful metrics*

---

- Resource Flow Variance (RV)
- Resource Flow Index (RI)
- Cost Variance (CV)
- Cost Index (CI)
- Schedule Variance (SV)
- Schedule Index (SI)
- Time Variance (TV)

*Besides computational formula, is there another way to estimate the values of these performance metrics?*

Yes, we can plot the following: ACWP, BCWP, BCWS,  
and then measure the performance metrics directly from the graph...



# 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

Figure by MIT OCW.

# Example: Schedule and Cost Index

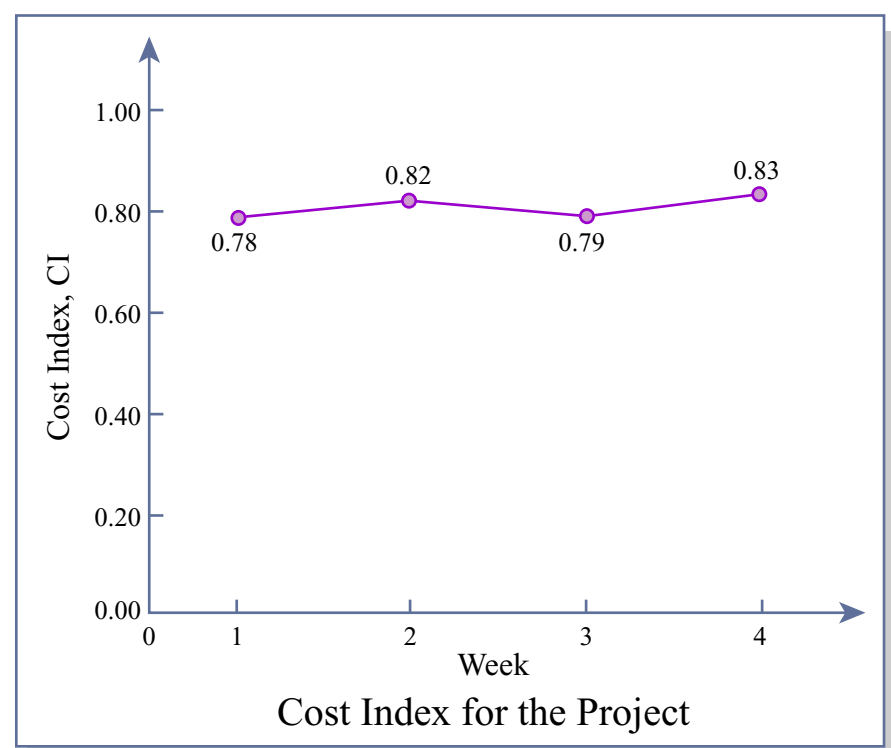
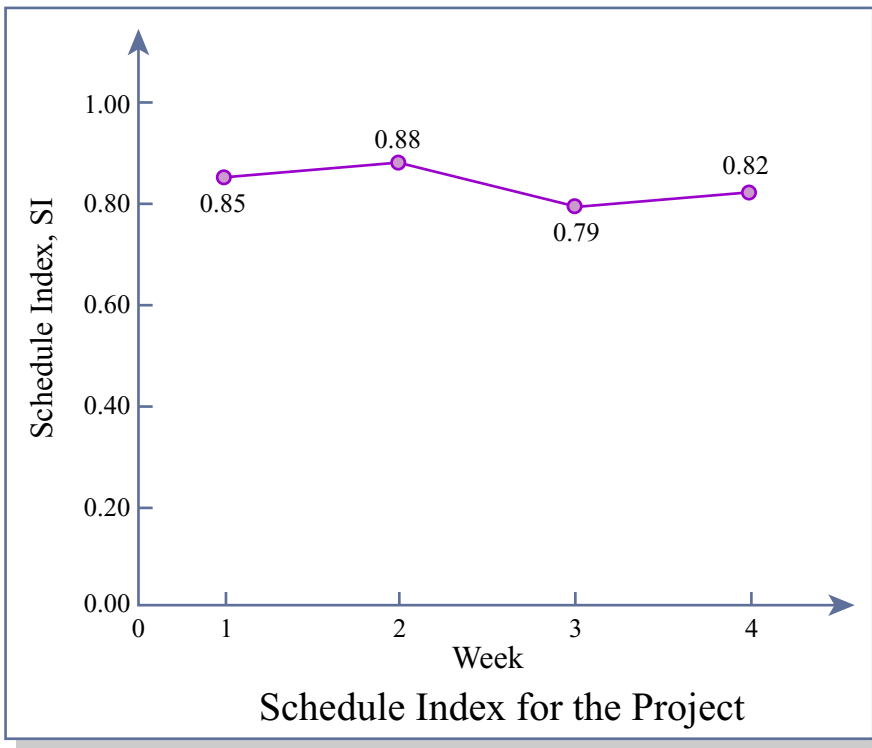


Figure by MIT OCW.

# Example: Integrating CI and SI

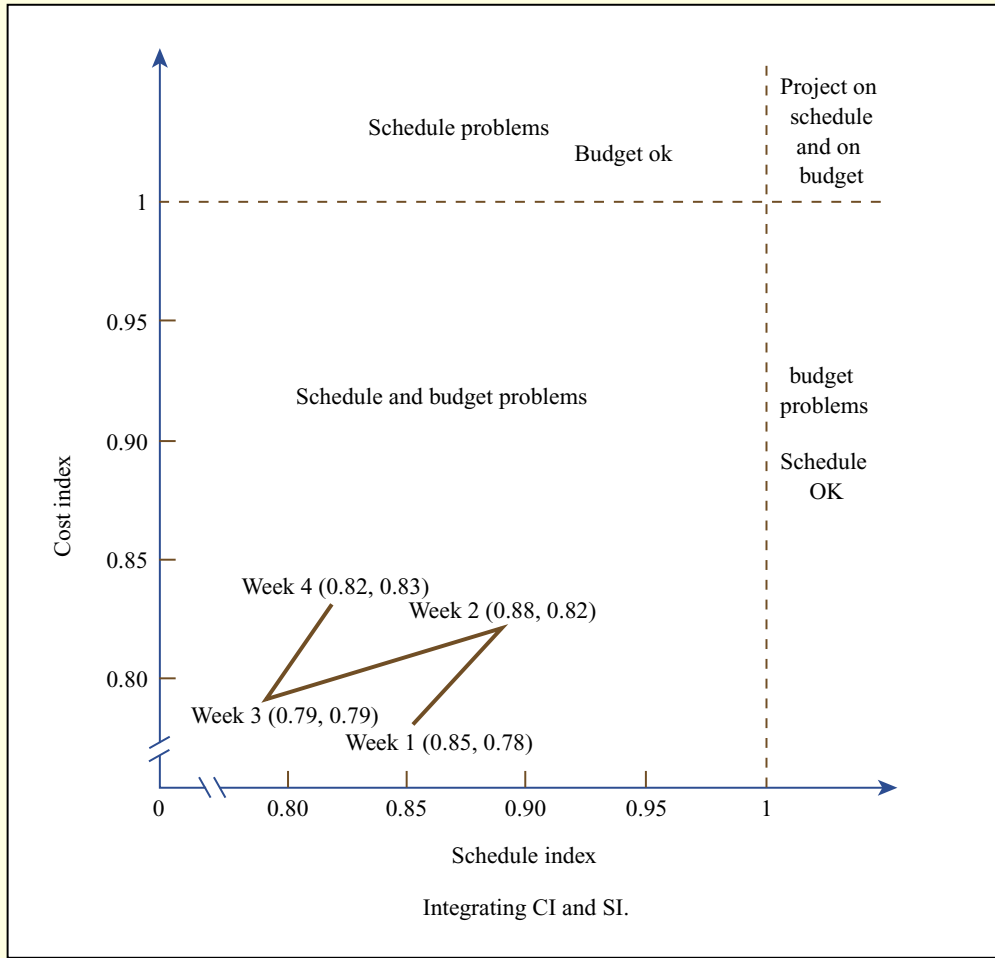


Figure by MIT OCW.





# Some Performance Metrics for Design and Procurement

# Some Performance Indices for Engineering/Design

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$$\text{Punctuality in issuing drawings} = 100 \times \frac{\text{\# issued drawings at current date}}{\text{\# drawings scheduled to be issued at T}}$$

$$\text{Owner approval process perf index} = 100 \times \frac{\text{\# approved drawings at current date}}{\text{\# drawings scheduled to be approved at T}}$$

$$\text{Manhours per progress point} = \frac{\text{Manhours spent}}{\text{Actual progress points}}$$

# Some Performance Indexes for Procurement

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$$\text{Punctuality of placed orders} = \frac{\text{\# placed orders at T}}{\text{\# orders to be placed at T}} \times 100 \%$$

$$\text{Punctuality of materials on site} = \frac{\text{Quantity of material on site at T}}{\text{Quantity of material to be on site at T}} \times 100 \%$$

$$\text{Quantity on site per progress point} = \frac{\text{Quantity on site at T}}{\text{Actual progress points}}$$



Have a good weekend!