Today’s Agenda

- Project Dynamics: Feedback Loops
- Qualitative Lessons
- Quantitative Models
- Validation and Model Extensions (if time)
The Problem ...

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Dynamics of Project Performance

- The “rework cycle”
  - Fraction correct and complete
  - Undiscovered rework

Feedback effects on productivity and fraction correct

- Negative, controlling
- Positive, re-enforcing, often “vicious circles”

Knock-on effects between work phases

- Availability and quality of work products
- Progress to discover upstream rework
Something Goes Wrong

Typical changes add 25% to original workload
The “Iron Triangle”

Cost

Scope

Project

Schedule

What happens when something goes wrong?
When your project falls behind schedule, what can you do to get it back on track?

1. Add people?
2. Work longer hours?
3. Work more “intensely” (including cutting corners, increasing concurrency, releasing work earlier than ideal)?
4. Slip the schedule?
5. Cut scope?
6. Other?

*We’ll discuss results in my lecture in two weeks.*
What do you do at ~30% complete?

What is your (company’s) response? Put a 1 next to your primary response, at 2 next to your secondary response, and so on. If you would not use a response, leave it blank, otherwise try to rank the options even if you rarely use them in practice.

1. Add people?
2. Work longer hours?
3. Work more “intensely” (including cutting corners, increasing concurrency, releasing work earlier than ideal)?
4. Slip the schedule?
5. Cut scope?
6. Other?
What do you do at ~65% complete?

What is your (company’s) response? Put a 1 next to your primary response, at 2 next to your secondary response, and so on. If you would not use a response, leave it blank, otherwise try to rank the options even if you rarely use them in practice.

1. Add people?
2. Work longer hours?
3. Work more “intensely” (including cutting corners, increasing concurrency, releasing work earlier than ideal)?
4. Slip the schedule?
5. Cut scope?
6. Other?
Management Reacts ...

- Productivity
  - Effort Applied
    - Fraction Correct and Complete
    - Work More
    - Work Faster or "Slack Off"
  - Work Intensity
    - Overtime
    - Workforce
    - Add People
    - Hiring
    - Effort Needed
    - Time Remaining
    - Deadline

- Original Work to Do
  - Effort Applied
    - Work Done
  - Rework to Do
    - Rework Discovery
    - Rework Generation
    - Undiscovered Rework
    - Known Work Remaining

- +
-
On a Typical Project, Productivity & Fraction Correct Vary Over Time

Why?
Why?

- **Side-effect feedbacks (often “vicious circles”)**
- **Knock-on or domino effects within or between work phases**
- **Knock-on or domino effects between projects**
Benchmarking Data -- Average ‘Quality’

Actions and Consequences

Control Action

- Hiring
- Overtime
- Work more intensely

Side Effects


Each Controlling Action Initiates Vicious Circles...

Make less progress, and more mistakes, than we thought

Experience

Effort

Productivity

Fraction Correct and Complete

Time Remaining

Deadline

Effort Needed

Hiring

Add People

Workforce

Deadline

Experience Dilution

Effort Applied

Applied

Known Work

Remaining

Time

Remaining

Effort Needed

Effort Needed

Hiring

Add People

Workforce

Deadline

Experience

Dilution
Experience Dilution

Congestion, Communication Difficulties

Too Big to Manage

Fraction Correct and Complete

Effort

Applied

Workforce

Hiring

Add People

Effort Needed

Time Remaining

Deadline

Known Work Remaining

Rework Discovery

Original Work to Do

Progress

Rework Generation

Rework to Do

Undiscovered Rework

Work Done
Overtime ➔ Fatigue and Burnout
Errors Create More Errors

Productivity

Fraction Correct and Complete

Effort Applied

Known Work

Remaining

Time Remaining

Effort Needed

Deadline

Add People

Hiring

Work Faster or "Slack Off"

Work Intensity

Work More

Haste Makes Waste

Fatigue

Experience

Congestion & Communication Difficulties

Burnout Effect

Rework Discovery

Rework to Do

Undiscovered Rework

Progress

Rework Generation

Original Work to Do

Work Done

Scope Growth

Unknown Errors in Prior Work

Errors Build Errors

Errors Create More Errors

Fatigue

Experience

Too Big to Manage

Burnout Effect

Haste Makes Waste

Work Intensity

Haste Makes Waste

Work More

Work Faster or "Slack Off"

Time Remaining

Deadline

Effort Needed

Add People

Hiring
Today's Agenda

- Project Dynamics: Feedback Loops
- Qualitative Lessons
- Quantitative Models
- Validation and Model Extensions
Project Behavior

Productivity and Fraction Correct Feedbacks

Rework Cycle Effects

- Delay and disruption
- Cumulative Impact
- Secondary impact
- Ripple effects
Qualitative Insights

- Undiscovered Rework is one of the most important single factors driving schedule and budget overruns.

- Most management reporting systems overestimate real progress and discourage reporting of rework.

- Management actions to control a project can initiate reinforcing feedback loops that cause project problems to “snowball” and amplify costs far in excess of the cost of triggering event.

- “Soft Factors” such as fatigue and morale can be big drivers of productivity loss and rework.
In your organization, what do you estimate is the relative contribution of the direct costs of External Changes and the costs of Management Responses to project overruns:

1. Costs of External Changes greater than costs of Management Responses
2. Costs of Management Responses greater than costs of External Changes
3. Costs of both about same
4. Varies too much by project to say for sure
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- Project Dynamics: Feedback Loops
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Hard tools force us to be more explicit, and accurately simulate the consequences of our models ...

“Soft” tools --

- behavior-over-time graphs
- cause-effect diagramming
- mental simulation

“Hard” tools --

- computer models
- computer simulation
- calibration to data
- sensitivity and what-if analyses

*Tools for describing dynamics*  
*Tools for quantifying dynamics*
Focus – Development of Computer Models

- More detailed stock/flow – causal diagrams
- Details of policy controls and side effects
- Some equations
- More detail in textbook chapter SD3
Purpose

- Understand enough of how model works to
  - Understand simulation results in next lectures
  - Execute policy tests and explain results in HW#3 and HW#5
  - Generate insights into improved practice
- Use and extend model on projects or other applications
We will use two models ...

1. Simple rework cycle model with project control/side-effect feedbacks
   - HW#3 – develop simple model without feedbacks
   - Feedbacks added in class, given in HW#5

2. Full rework cycle model with two phases of work
   - No project control feedback
   - Model given to you for HW#3 and HW#5
Project Model 1: Simple Rework Cycle

Rework cycle model (HW#3)

- Three stocks
- Variable rework discovery time
- “Errors Build Errors” Feedback

*Model you develop in Part 1 of HW#3*
Two Views of the Rework Cycle

**Complete Model**

The simplified version assumes that rework tasks require the same effort as original tasks, and that it is not important to distinguish between original work and rework.

**Simplified Version**
Simple Rework Cycle Model

Steps 1-4 of Homework #3
Rework Discovery Depends on Progress

Delay in Discovering Rework
This reflects the average delay in discovering discoverable rework, such as from QA activities or downstream work.

Fraction of Rework Discovered
This reflects the fraction of undiscovered rework that is discoverable at any point in the project based on the activities taking place.

Fraction Really Complete

Graph Lookup - Fraction of Rework Discovered

Fraction Really Complete

0 0 1
Complete Simple Model 1

"Errors on Errors" Feedback

- Sensitivity of Fraction Correct to Undiscovered Rework
- Maximum Effect of Undiscovered Rework on Fraction Correct

No project monitoring or adaptation "control"
Representing Effects on Productivity and Fraction Correct
Productivity --

PRODUCTIVITY =

Dimensions:
- Productivity --
- Normal Productivity --
- Effects --
Fraction Correct --

- Fraction Correct = Normal Fraction Correct * Effect of Staff Experience * Effect of Undiscovered Rework * ...

- Dimensions:
  - Fraction Correct -- Fraction
  - Normal Fraction Correct -- Fraction
  - Effects -- “Dimensionless”
Effect of Staff Experience

Effect of Experience = Function (Months on Project)
How do we determine these effects?

- The effects are first estimated based on “common sense.”
- Specify likely values at extreme points, and draw a smooth curve in between.
- Later, effects verified via model calibration and/or sensitivity testing.
Effect of Staff Experience

Effect of Experience = Function (Months on Project)
Effect of Undiscovered Rework on Fraction Correct:

Graph Lookup - Table for Effect of Prior Work Quality on Quality

Effect of Undiscovered Rework on Fraction Correct

Decrease in "Sensitivity" from 1 to 0

Graph of Fraction Correct vs. Fraction of Work Believed Done Correct and Complete

Note: The effect of undiscovered rework on fraction correct is assumed to be proportional -- an error in past work creates an error in current work. Given that in this simple model fraction correct represents several effects of work errors, this strong relationship may be reasonable.
HW#3 Part 1 CityCar Simulation

**Work Done**

- No Rework
- Rework

**Staff**

- No Rework
- Rework

Tasks vs. Time (Week)

- Work Done: HW3 Step6
- Work Done: HW3 Step3

People vs. Time (Week)

- Staff: HW3 Step6
- Staff: HW3 Step3
Project Model 2: Work Flows & Staffing in “Simple” Two Phase Model

Model you are given in Part 2 of HW#3
Design Phase of Work (Build/Test Similar)

Allocation of Staff Based on Backlogs, etc.

"Errors Create Errors" Feedback

Rework Discovery
### Key Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Design</th>
<th>Build/Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Productivity (Tasks/Week/Person)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Normal Fraction Correct and Complete (Fraction)</td>
<td>0.6</td>
<td>0.95</td>
</tr>
<tr>
<td>Relative Effort Required for Rework</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Priority to Original Work</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Max Sensitivity of Fraction Correct to In-Phase Undiscovered Rework</td>
<td>0.5</td>
<td>0.75</td>
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<tr>
<td>Max Sensitivity of Fraction Correct to Inter-Phase Undiscovered Rework</td>
<td>NA</td>
<td>1</td>
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<tr>
<td>Max Sensitivity of Productivity to Undiscovered Rework</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Max Fraction of Design Rework Discoverable by Design Work</td>
<td>0.6</td>
<td>NA</td>
</tr>
<tr>
<td>Fraction of Design Rework Discovered Based on Planned Iterations and Reviews</td>
<td>0.3</td>
<td>NA</td>
</tr>
<tr>
<td>Fraction Design Complete to Start Build Ramp-up</td>
<td>NA</td>
<td>0.99</td>
</tr>
<tr>
<td>Duration of Ramp-Up</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Rework Discovery

Max Fraction Discoverable in Design = 0.6

Graph Lookup - Effect of Design Progress on Design Rework Discovery

Graph Lookup - Design Effect of Build Work on Rework Discovery

Design Fraction Original Work Complete

Build/Test Fraction Original Work Complete
HW#3 Part 2 *CityCar* Simulation

**Design Work Done**

- **No Rework**
- **Rework**

**Build/Test Work Done**

- **No Rework**
- **Rework**

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Project Model 1: Elaboration

- Rework cycle model (HW#3)
  - Three stocks
  - Variable rework discovery time
  - “Errors Build Errors” Feedback

- Project control & Side Effects (HW#5)
  - Work Intensity/Schedule Pressure & “Haste Makes Waste”
  - Staffing & Experience Dilution
  - Slip Schedule
Where we are headed – Full One-Phase SD Model!!

Project Control

Side Effects

HW#3 Model
Example Project

- Scope = 1000 Tasks
- Scheduled Completion Date = 30 (Month)
- Staff = 40 (Implied budget of 1200 person-months, including 200 tasks estimated rework)
- Normal Quality = 0.85
- Productivity = 1 task/month/person

Note: Infeasible Plan
Project Behavior

Cost = 1570 person-months

Total Tasks = 1570

How do we control project to get it done on time?

Work Done : Class3 Base No Project Control
Cumulative Work Done : Class3 Base No Project Control
Staff for Output : Class3 Base No Project Control

Staff & Progress

0 6 12 18 24 30 36 42

Time (Month)

2,000 Tasks
100 People

1,000 Tasks
50 People

0 Tasks
0 People

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1. Project control is driven by estimates of how much effort is left ...

2. Estimates are based on work to do and productivity (undiscovered rework?)
Project Control -- Staffing

How many people do I need to get the job done on time?

Staff Required = Estimated Effort Remaining / Time Remaining [People]
How many people do I need to get the job done on time?

When Can I finish with the current staff?

Indicated Completion Date = Time + \( \frac{\text{Estimated Effort Remaining (Person-Months)}}{\text{Staff}} \) [Month]
Project Control

Based on Staff Required and Indicated Completion Date, three options:

1. Add Staff
2. Explicitly Slip Schedule
3. Exert “Schedule Pressure” (Work Intensity and Extra Hours)
Actions Determined By ...

To the extent these do not sum to 1, work/schedule pressure is residual.

"Willingness to Hire (0-1)"

"Willingness to Slip (0-1)"
Work / Schedule Pressure
Work/Schedule Pressure

- If a project falls behind schedule and staff are not added or schedule slipped, management...
  - Pressures team to work faster
  - Team works longer hours/overtime

→ Represented as impact on “effective staff” ( = staff * intensity-overtime ratio)
Schedule Pressure

Downsides (Side Effects) --

- “Haste makes waste”
- Fatigue adds to mistakes (and may reduce productivity)

Represented as impact on fraction correct and complete, and on productivity
Added an effect on P and FCC
Subject to maximum intensity/hours worked (currently 2)

Effective Staff = Staff * Work Intensity/Hours Worked

Willingness to Use Intensity & Extra Hours

Work/Schedule Pressure = Staff Required/Staff

0 - 1

Effective Staff = Staff * Work Intensity/Hours Worked

Work/Schedule Pressure = Staff Required/Staff

0 - 1
Without Secondary Impact …
The project finishes sooner

Total Effort Expended

Control, No Secondary Impact
No Project Control

0 6 12 18 24 30 36 42 48 54 60
Time (Month)

0 500 1,000 1,500 2,000
Person-Month

Total Effort Expended : Class3 Base WI-OT No SI
Total Effort Expended : Class3 Base No Project Control
Impact on Productivity & Fraction Correct

- Lagged Intensity/Extra Hours for Rework
- Effect of Intensity/Hours on Fraction Correct
- Work Intensity/Hours Worked
- Lagged Intensity/Extra Hours for Productivity
- Effect of Intensity/Hours on Productivity
- Effective Staff
- Work/Schedule Pressure
- Staff
- Time to Perceive Work Pressure
- Staff Required
- Time Remaining
- Estimated Effort Remaining (Person-Months)
- Scheduled Completion Date

Willingness to Use Intensity & Extra Hours

+ Impact on Productivity & Fraction Correct

- Estimated Effort Remaining (Person-Months)
- Staff Required
- Time Remaining
- Estimated Effort Remaining (Person-Months)
- Scheduled Completion Date

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Key Parameters: Impact Sensitivity and Delay

How long does it take before Intensity/Longer Hours affects Productivity and Fraction Correct?

How strong is the effect?
Impact determined by “sensitivity”

- **Productivity**
  - Sensitivity = 1 $\Rightarrow$ productivity falls such that *additional* output is zero
  - Sensitivity = 0 $\Rightarrow$ no reduction in pdy
  - Sensitivity = 0.5 $\Rightarrow$ *additional* output 50%

- **Fraction Correct**
  - Sensitivity = 1 $\Rightarrow$ all *additional* output contains errors
  - Sensitivity = 0 $\Rightarrow$ no reduction in fraction correct
  - Sensitivity = 0.5 $\Rightarrow$ *additional* output 50% errors

*See text for implementation details (SD3.4.2, pp. 27-34).*
Staffing
Staffing Added to Model

Added an effect on P and FCC
Effect = \((\text{New Staff} \times \text{Relative Experience of New Staff} + \text{Experienced Staff}) / \text{Staff Level}\)

- **Effect of Experience on Productivity and Fraction Correct**
- **Time to Gain Experience**: 6 months
- **Staff Level Required to Complete on Schedule**: 40

Really “Time to Reach Full Productivity”
Adding 4 New Staff at Time 2

**Staff**

- **New Staff**: Current People
- **Experienced Staff**: Current People

**Effect of Experience on Productivity and Quality**

- Dimensionless

### Graphs:

- **Staff Graph**
  - Time (Month) from 0 to 50
  - New Staff and Experienced Staff trends over time

- **Effect of Experience Graph**
  - Time (Month) from 0 to 50
  - Effect of experience on productivity and quality over time

---

New Staff : Current People
Experienced Staff : Current People

Effect of Experience on Productivity and Quality : Current Dimensionless
We’ll discuss simulations of secondary impact in two weeks and in HW#5.
Changing Schedule
(see textbook)
Full SD Model (Chapter 3)
Planning Assumptions

- Scope = 1000 tasks
- Estimated Rework = 200 tasks
- Scheduled Completion Date = 30 (Month)
- Staff = 40 (Implied budget of 1200 person-months, including 200 tasks estimated rework)
- Normal Quality = 0.85
- Productivity = 1 task/month/person
Project Controls

- Willingness to Hire
- Willingness to Slip
- Willingness to Use Intensity & Extra Hours

Note: Should add to 1.0?
Secondary Impacts

- Relative experience of new staff
- Time to gain experience
- Sensitivity for effect of intensity/extra hours on productivity
- Sensitivity for effect of intensity/extra hours on rework
- Time for pressure to effect productivity
- Time for pressure to effect rework
Today’s Agenda

- Project Dynamics: Feedback Loops
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Additional Issues

1. Model validation
2. Model extensions and elaborations

These are discussed in textbook Chapter SD3.
Model Validation

- Does the structure reflect what happens on projects?
  - Rework Cycle?
  - Staffing Dynamics?
  - Project Controls?
  - Effects on productivity and fraction correct?
- Are the parameters reasonable?
How do we know the “real” effects?

- Relative experience of new staff?
- Sensitivity of productivity and rework to overtime?
- Time delays for impact?
You’re Uncomfortable With Quantifying All These Effects. What Are Your Options?

1. Ignore effects and estimate (simulate) impacts as if they did not exist
   - But that’s the only value you know is wrong!

2. Use your experience/intuition/ “mental model” instead (no simulation)
   - I.e., try to account for effects simultaneously in your head that you can’t do individually in a computer model

3. Use computer model with educated estimates ...
   - Test sensitivity of results to exact values
   - Gather data and calibrate where warranted
Summary of *Computer* Model

- Three effects on Productivity & “FCC”:
  - Errors on Errors
  - Work/Schedule pressure (represents overtime, fatigue, out-of-sequence work)
  - Experience (represents staff diversion & training, size of organization)
- Decisions to increase or reduce staffing
- Decisions to change scheduled completion date
Are There Alternative Models?

- More Productivity & “FCC” effects, etc.
- Variations on the basic rework cycle
- Multi-project and organizational models
More Productivity and Fraction Correct & Complete Effects:

- Model has 3 effects on P & Q:
  - Errors on Errors
  - Schedule pressure
  - Experience

- What additional affects could be included?
  - Morale
  - Overtime/fatigue
  - Sequence
  - Other types of experience
  - # projects/person
  - Organizational Size Changes
  - Availability of supplier information
  - and materials
  - Skills match to needs
  - ...
A model might separately represent different drivers of experience, e.g.:

- Effect of Experience on Project = Function (Time on Project)
- Effect of Experience in Field = Function (Years Working)
- Effect of Skill = Function (Inherent Skill)
- Learning (Fraction Complete?)
Discussion – Representing Experience

- Experience on Project
  - Relative productivity = 0?
  - Time to gain experience fraction of project duration

- Experience as Engineer
  - Relative productivity = ?
  - Time to gain experience = duration of project or longer
Other Stocks

- Budget
- Knowledge
- Morale
- Technology
- Priority of Project
- Scope/features/customer needs
- Other resources
Other simplifications?

- Task dependence/sequence is not represented explicitly -- with enough staff, could finish the project in a week
- Only one phase of work explicitly represented
- Suppliers are not represented
- Interactions with other projects are not represented

*These are treated endogenously or exogenously in more comprehensive models.*
The “Iron Triangle”

Cost

Scope

Project

Schedule

What happens when something goes wrong?
Other Responses?

- To achieve target schedule ...
  - *Add resources*
  - Reduce scope
  - Ship with “bugs”
  - …

- To achieve target cost (total vs annual spend)
  - Reduce scope
  - Ship with “bugs”
  - Slip schedule to control annual spend
  - …

- To achieve target scope ...
  - *Add resources*
  - Slip schedule  
    *Focus on achieving (1) scope & (2) schedule …*
When is the project finished?

- In the current model, keep working until all work is completed correctly. In other situations, schedule may be more critical and therefore the project might:
  - reduce scope to meet schedule
  - ship with errors ( undiscovered rework)

We will discuss other options later in term ...
ESD.36 System Project Management
Fall 2012

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