Dynamics of Project Performance

System Dynamics and Project Management

Class Three (9/30/03)
Topics

• Review Practice for 9/30

• The dynamics of project performance -- knock-on effects

• Modeling the feedback effects

• Model Calibration

• Practice for 10/2
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What did you conclude re. the effect of productivity, quality, and rework discovery time on time required to finish the project?
Sensitivity of Completion Date to +/-33% Variation in Parameters

Quality - Completion Date

Productivity - Completion Date

Rework Discovery Delay - Completion Date
Sensitivity of Total Work Done to +/-33% Variation in Parameters

Quality - Total Work Done

Productivity - Total Work Done

Rework Discovery Delay - Total Work Done
Sensitivity of Completion Date

- Variations in Quality have biggest impact --
  - Nonlinear effect
  - Determines total amount of work

- Rework discovery time has the least impact (but the simple model does not have a quality on quality feedback).
Graph for Undiscovered Rework

Quality = .5

Quality = .75

Quality = 1.0

Time (Month)

Undiscovered Rework : Class2 Step1
Undiscovered Rework : Class2 Step1 Q100
Undiscovered Rework : Class2 Step1 Q50

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Rework Shows Up As Revised Work Products

Accomplishment of Revisions to Design Products (e.g., Drawings)

Virtually all complex projects have revision cycles.

REV 0

REV 1

REV 2

REV 3...

TIME
Managing the rework cycle

- Do common project metrics handle (undiscovered) rework?

- Do management incentives encourage the discovery of rework?
Additional Metrics (Used in Model)

- Fraction Perceived to be Complete = 
  \( \frac{\text{Work Done} + \text{Undiscovered Rework}}{\text{Initial Work to Do}} \)

- Fraction of Work Really Complete = 
  \( \frac{\text{Work Done}}{\text{Initial Work to Do}} \)
Perceived vs. Really Complete in Simple Rework Cycle Model

Progress

Fraction Perceived to be Complete : Step2
Fraction Really Complete : Step2

Time (Months)

Fraction

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On an actual project

Perceived vs. Actual Progress: SRS Development

Disguised results from actual aerospace project
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Examples of Project Behavior Modes

Project Staffing

Typical Plan

Time
Examples (continued)

Productivity (Normalised)

Typical Plan

Time
Dynamics of Project Performance

The “rework cycle”
- Quality
- Undiscovered rework

Feedback effects on productivity and work quality
- Positive, re-enforcing, often “vicious circles”
- Negative, controlling

Knock-on effects between work phases
A system dynamics model usually represents several phases of work, but is more aggregate than a CPM model.
Peace Shield Air Defence System Model Architecture

Software System Engineering

Software Development

SRS Development

Top Level & Detailed Design

Code & Unit Test

Integration & Type II Test

Type I Test

KOSA SW & Testing

CONUS

Program Management Office

Customer

Hardware

Logistics

Subcontractors

Other HASI Programs

Op. & Main/ILS

HW Installation & ICO Test

Mgt. & Admin.

Downstream Progress, Availability, & Quality Effects

Upstream Rework Discovery Effects

Support Effects

Upstream Rework Discovery Effects

Support Effects

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Inter-phase Effects

Downstream &/or Parallel --
- Availability of work products
- Quality of work products

Upstream --
- Rework discovery

Above apply internally and to suppliers

General --
- Sharing of staff
Inter-phase Connections: Upstream-Downstream

Design

Progress; Quality

Construction

Productivity   Quality

Progress
Inter-phase Connections: Parallel

Software Design

Progress: Quality

Hardware Design

Progress: Quality

Productivity | Quality
---|---

Inter-phase Connections: Parallel

Software Design

Progress: Quality

Hardware Design

Progress: Quality

Productivity | Quality
Dynamics of Project Performance

The “rework cycle”
- Quality
- Undiscovered rework

Feedback effects on productivity and work quality
- Positive, re-enforcing, often “vicious circles”
- Negative, controlling

Knock-on effects between work phases
- Availability and quality of work products
- Progress to discover upstream rework
How might we represent suppliers? ... platforms? ...
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  - *Modeling the feedback effects*
  
- Model Calibration
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If the world consists only of stocks and flows, what are those other variables indicated on the diagrams?

- “Auxillaries”
- Constants (e.g., factors which may be stocks or flows, but which do not change over the time span of the simulation)
- External inputs
Auxillaries or “Converters” Serve Several Purposes ...

- Break up rates into meaningful components
- Provide alternative measures for stocks or flows
- Reduce diagram “clutter”
Potential Work Rate

Potential Work Rate = Staff * \textit{Productivity}

Tasks/Month  People * Tasks/Month/Person
Productivity & Quality

- Productivity = ??
- Quality = ??
Productivity --

- PRODUCTIVITY = NORMAL PRODUCTIVITY * EFFECT OF STAFF EXPERIENCE * EFFECT OF QUALITY OF PRIOR WORK * ...

- Dimensions:
  - Productivity -- Tasks/Month/Person
  - Normal Productivity -- Tasks/Month/Person
  - Effects -- “Dimensionless”
Quality --

- QUALITY = NORMAL QUALITY * EFFECT OF STAFF EXPERIENCE * EFFECT OF QUALITY OF PRIOR WORK * ...

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

- Effect of Experience = Function (Years on Project)
Effect of Staff Experience

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

- The effects are first estimated based on “common sense,” later to be verified during model “calibration.”

- It helps to specify likely values at extreme points, and draw a smooth curve in between.
Effect of Staff Experience

Extreme points --

Years on Project

0  2  4  6  8  10

0.0  0.2  0.4  0.6  0.8  1.0

?
Connecting the extreme points ...
Some other “connections” are plausible ...
Others are not ...
Relationships Similar to the Experience Effect Would Be Specified For Other Effects on Productivity and Quality

- Experience
- Adequacy of supervision
- Availability of resources
- Morale
- Schedule pressure
- Fatigue
- Quality of prior work
- Skills available vs. needs

- Tools
- Processes
- Availability of supplier information &/or materials
- ...

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Note difference with statistical estimation --

Productivity = a + b*experience + c*prior quality
Rules of Thumb and Checks

1. Variables and constants should correspond to real system variables
2. Remember to represent delays -- in flow channels, in perceiving information, and in making or implementing decisions
3. Distinguish desires from realizations
4. Make sure that equations balance dimensionally
5. Check the validity of equations at extreme points, e.g., zero or very high values of the inputs
6. Avoid the use of imbedded functions -- they make the equations harder to understand and can lead to errors
... from a student’s email:

On a couple of occasions in lecture yesterday you discussed "Overtime" as it relates to "Morale". In doing causal loops, I find that the relationship between the 2 can be different and dependent on time. For example, initially the morale of employees may increase or support the increase of overtime which provides a positive relation between the 2. However, as the overtime continues, I believe the morale will decrease as employees will start to desire a life outside of work which supports a negative relation between the 2.

I guess that in the actual SD modeling the developer would create a curve/equation for morale over time, but what about for causal loops? How do you handle the dynamics with causal loops? Maybe the loops are just an initial starting point for the development?
Representing morale …
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Calibration (Parameter Estimation)
A *priori* estimates based on

- direct observation
- educated guesses by managers
- similar parameters from other applications

Refine initial estimates in the process of calibration
Calibration is part of the scientific method

Calibration is not curve-fitting via exogenous variables, but systematic comparison of model output to all “data” and resolution of any discrepancies

- changes in structure
- changes in parameters
- decision to ignore (or sometimes use exogenous effect)
Calibration Should Be a Part of the “Standard Method”

- Data is a real source of information
- Calibration often uncovers errors/omissions in insight-based models
- Cost is small relative to the stakes in most large organizations
Why do we calibrate a model?

- Assure model contains all of the structure necessary to create problem
- Accurately determine leverage points
- Accurately price cost-benefits of alternatives
- Sell results to those not on project team
- Generate a benchmarking data base for future use and learning
Sources of information for calibration

- “Hard,” numerical time series (e.g., for staffing, work accomplished, overtime levels, etc.)
- “Soft,” management “observations” of what happened (e.g., how morale, experience, and other factors might have caused productivity and quality to change)
  - such observations must be tied to what was happening on the project
Once calibration is completed …

We have a model that is useful for:

- Learning
  - what really happened on prior projects
  - what could have been done better
- Dispute resolution
What happens if you can’t calibrate?

- Use logical parameter estimates
- Simulation model still better than mental models
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Lessons

- Rework (Errors) Can Linger for Long Periods of Time as “Undiscovered Rework”
- Reducing Rework, and Detecting it Earlier, is the Best Way to Cut Cycle Times, Finish Earlier, and increase Delivered Quality
- Common metrics & reward systems do not encourage high quality and rework discovery
- Interactions between phases of work, different projects, suppliers, create opportunities for “knock-on” effects
- Calibration will improve the accuracy of our parameter estimates, and ultimately policy decisions
1. Download the Class2 Step2 model. This is the rework cycle model with a variable time to discover rework. Time to discovery rework, as illustrated in the following figure, depends on a maximum time and a minimum time, and an effect of work progress. Time to discover rework falls from the maximum to the minimum time as fraction complete increases.
Rework cycle with variable time to discover rework
2. Add the effect of prior work quality on quality as discussed in class and illustrated in the following figure.

3. Simulate the model and compare to the original Class2 Step 2 results. How does the addition of “quality on quality” feedback affect project performance?

4. If we essentially eliminate undiscovered rework by setting the maximum time to discover rework to 0.25 months, what happens to project performance?
Effect of Prior Work Quality on Quality:

Note: The effect of prior quality on current quality is assumed to be proportional -- and error in past work creates an error in current work. Given that in this simple model quality represents several effects of work errors, this strong relationship may be reasonable.
Hints -- 2

Average Work Quality:
Max(1e-006, Work Done)/Max(1e-006, Work Believed to Be Done)

[Note: the max in the denominator prevents division by 0, and in the numerator allows the equation to return a quality of 1.0 when no work is yet completed.]
Hints -- 3

Normal Quality:
Set this to 0.85 (vs. 0.75 in Class2 Step2 model) to reflect that we are now explicitly representing other factors affecting project quality.
Graphical Functions in Vensim
Step 1 - Set Up Model As Shown Below

Normal Quality → Quality

Effect of Prior Work Quality

Table for Effect of Prior Work Quality

Average Work Quality
Step 2 -- Equations ... 

Quality = Normal Quality*Effect of Prior Work Quality

Effect of Prior Work Quality = Table for Effect of Prior Work Quality(Average Work Quality)
Step 3 -- Define the Table

Click to define equation for “Table for Effect of Prior Work Quality”
Select the “Type” as “Lookup”
Click on the “As Graph” button to see the function
You can then type in values or create a line on the blank graph
You can edit the values directly if desired
Voila!

Table for Effect of Prior Work Quality:

<table>
<thead>
<tr>
<th>Prior Work Quality</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
In the short-term, overtime increases morale and productivity …
But in the longer-term, sustained overtime reduces morale and productivity ...
Connecting the feedbacks through progress ...