Systems Thinking and Project Management

- **Primary critique:** Traditional methods too
  - Fragmented
  - Restrictive in assumptions
  - Local in attention to implications of changes
  - Hesitant regarding representation of “soft” factors
  - Too dependent on people link components
  - Too willing to ignore important “side effects”

- **Seen as potentially major contributor in project**
  - Learning (model captures institutional knowledge)
  - Planning (identify robust decision rules, leverage pts)
  - Control (how to best handle deviations)
Evolving More Complex Diagrams
System Dynamics Basics

- Represents system as coupled series of ordinary differential equations (ODEs)
  - Standard state-equation formulation
  - Continuous time formulation
  - Stochastic components permissible (special handling)
  - Analytic solutions not possible: Numerically integrate

- Graphical representation for problem focus
  - State equations as stocks
  - Components of differentials as follows
  - Intermediate computations as auxiliaries, table functions, etc.
How a SD Model is Created

- Conceptualize system using causal loop diagram
- Convert CLD to “stock & flow” *structure*
  - State variables (accumulations) as stocks
  - Changes to state variables as flows
    - All *change* in system state occurs through *flows*
  - All loops include at least one stock
  - Intermediate calculations, outputs as auxiliaries
- Add to equations to capture relations among vars
- Calibrate to historic data
- Run scenarios to identify effect, robust policies
Example Creation of a System Dynamics Model

- **Step 1: Map out Causal Loops**
- **Step 2: Identify state variables of interest**
- **Step 3: Identify flows of interest**
Example Creation of a System Dynamics Model

- **Step 4: Define Supporting Variables**

  - Insert equations to describe linkages
    - **E.g.**
      - **Total Population = Customers + Potential Customers**
      - **Fraction of Customers in Population = Customers / Total Population**
Example Creation of a System Dynamics Model II

- **Step 1: Map out Causal Loops**
- **Step 2: Identify state variables of interest**
- **Step 3: Identify flows of interest**
Example Creation of a System Dynamics Model

- Work Hours as a Function of Fraction of Work Completed
- Fraction of Work Completed
- Work Remaining
- Normal Productivity
- Work Being Completed
- Work Hours
- Normal Work Hours
- Fatigue
- Growth in Fatigue due to Schedule Pressure
- Recovery from Fatigue
- Mean time to Recover From Fatigue
- Productivity Coefficient as a Function of Direct Work Pressure
- Productivity Coefficient from Fatigue
- Productivity Coefficient from Fatigue as a Function of Fatigue
Statistics

• Statistics can assist in calibrating relationships in a model

• Remember that there are typically many indirect effects not shown!
Examples of How We Use a System Dynamics Model

- Typical first step: Assume some “baseline” scenario
  - Just point of reference – not particularly privileged

- “Policy” scenario analysis
  - Change “policy parameters” (e.g. hiring policy, fraction change vs. rework, etc.) and look at results

- Policy robustness to uncertainty
  - For different policy parameters, examine implications of major points of uncertainty

- Sensitivity analyses (both of above, and to focus further data collection)

- Examine impact of different external conditions
Uncertainty in System Dynamics

- Often address uncertainty using sensitivity analysis
  - Goal is to see how much our *choices* depend on uncertainty

- Thorough analysis requires monte-carlo trials

- Two types of uncertainty
  - Static uncertainty (e.g. uncertainty about the value of a model parameter)
    - Specify distribution for model variable at start of run
  - Dynamic uncertainty (stochastic processes): Sample throughout simulation
Stochastic Process Monte Carlo

- Essentially numerically solving stochastic differential equation

![Graph showing time series data with time (Day) on the x-axis and price on the y-axis. The graph includes multiple trajectories with varying levels of sensitivity for individual trajectories.](image)
Monte Carlo Output

- Empirical fractiles shown with color coding

![Graph showing Monte Carlo output with color coding for different fractiles.](image-url)
Coexistence...or Integration?

- Road to (awkward) coexistence
  - System dynamics: “Dynamic” complexity
    - Interactions, time delays, feedbacks
  - Traditional tools: “detail” complexity
  - Problems: How to synthesize results? Which to trust? How to link models?
    - Most frequent: CLD for qualitative insight, traditional tools for quantitative tradeoffs

- Use of single model

- Integration: e.g. DPM
DPM: Construction Oriented Model

- Created by Park, Peña-Mora
- Includes components of network-based models
- Used to analyze real-life projects
- Notable components
  - Richer set of dependencies
    - Refinement of internal/external linkages
    - Dependencies between design acts. and construction acts.
  - Specification change/rework distinction, cycles
  - Characterization of “knock-on”
    upstream/downstream effects
Inter-Activity Dependencies

Example: Plumbing & Electrical
Roughing and Drywall

Example: Pouring of concrete and
erection of shoring for next floor
Internal Dependencies

Example: Subsequent Floors
Example: Site-Wide Drywall
Role of Quality

- DPM operationalizes quality as fraction of work that is acceptable according to specifications
- Quality problems often not discovered until later!
  - Decreasing time to discovery is key!
- Statically, we can expect higher quality to lead to:
  - Higher costs
  - Higher time to completion
- Dynamically, quality serves as a driver for:
  - Rework
  - Specification changes
Specification Change vs. Rework: Big Picture

Divergence in Task "X"

Managerial Decision

Make managerial change

Rework

Change in Task "Y"

Achieving the original plan associated with Task "X"
Rework

- **Common in other field (e.g. software)**
  - E.g. tendency to periodically rewrite software

- **Limited in construction**
  - Rework perceived as exorbitantly expensive
  - Delays in discovering quality problems may rule out
Specification Changes

- When divergence between specifications and as-built work, changes *specifications*
- Superficially attractive: Seems to limit in field changes
- Multiple types
  - Managerial changes (including owner requested)
  - Unintended changes
Unintended Changes

Upstream Hidden Change

Unintended Change

- Low Work Quality
- Poor Work Conditions
- External Scope Changes
Specification Changes vs. Rework in Construction: Tradeoffs

- **Rework**
  - More short-term work
    - Especially if delayed in discovering original divergence!
  - Limits extent of impacts

- **Specification Changes**
  - Less short-term work
  - Can lead to lots of “side effects” as specification changes propagate to other components of specification
Example of Change Propagation

- Conflicting drawings about duct routing leads to changes to one set of drawings to accommodate re-routing of ductwork from another fan room
  - Plumbing, electrical work reexamine routing
  - Need for larger HVAC unit requires
    - Re-working shop-drawings
    - Reexamination of electrical system for higher load
    - Reconsideration of piping supporting HVAC
    - Examination of structural loading of building

- Delays can affect customer relations, idle resources, interfere with other A/E activities, increase pressure…
Big Picture: Role of Flexibility

- Flexibility forms a critical ally against *risk of change*
- One pays for flexibility – but often pays more for lacking flexibility
Construction Overlap Feedbacks

- Uncertainties
- Assumptions in Design
- Owner's Requests on Changes
- Potential Design Change Impact on Construction
- Design Changes
- Construction Processes Overlapping
- Construction Work Done before Upstream Completed
- Estimated Project Duration
- Time Pressure
- Increase in Workforce
- Productivity
- Construction Changes
- R1
- R2
- R3
- Delay
- Oversizing
- Project Costs
- Project Duration
- Overlapping between Design and Construction
Big Picture:

Fast-Tracking and Overlapping of Activities Has Multiple Risks

- **Risk 1:** Greater risk of rework/changes
  - Starting out with less certainty as to how preceding activity (design or construction) will proceed

- **Risk 2:** Greater vulnerability to rework/change
  - Already in a hurry; schedule affords less slippage
  - More near-critical activities
Additional Feedbacks 1

Schedule Pressure

+ Delays

Focus on Short-Term Productivity

+ Change Ripple-Through Effects

Preference for Managerial Changes

+
Additional Feedbacks II

Delay

Supervisor Work Level

Impact of Changes on Schedule

Delay until Discovery of Discrepency

Likelihood of Overlooking a Discrepancy between Specifications and As-Built Work

Impact of Changes on Schedule

Delay until Discovery of Discrepency

Likelihood of Overlooking a Discrepancy between Specifications and As-Built Work

Supervisor Fatigue
Change Process Loop 1:
DS Pre-check Identifies Divergence
Change Process Loop 2: Divergence
Discovered During DS Work

- Time to Reprocess
- Delay
- Schedule Pressure
- Quality Management Thoroughness
- Willingness to Adopt Managerial Change
- Reprocess
- Reprocess Requests From Downstream
- Upstream Changes Discovered in Downstream
- Hidden Changes Released to Downstream
- Downstream Quality
- Downstream Reprocess
- R2

Willingness to Adopt Managerial Change
Downstream Reprocess

Upstream Changes Discovered in Downstream
Hidden Changes Released to Downstream

Downstream Quality
Downstream Reprocess

R2

Downstream Delay

Reprocess Requests From Downstream

Time to Request Reprocess from Downstream
Change Process Loop 3: Specification Change Adopted

- Reprocess
- Time to Reprocess
- Delay
- Schedule Pressure
- Quality Management Thoroughness
- Willingness to Adopt Managerial Change
- Upstream Changes Discovered in Downstream
- Hidden Changes Released to Downstream
- Time to Request Reprocess from Downstream
- Downstream Reprocess
- Downstream Quality
- Downstream Delay
- R1

Factors affecting Change Process Loop 3:
- Managerial Change Adoption
- Quality Management Thoroughness
- Schedule Pressure
- Delay
- Time to Reprocess
- Reprocess Requests From Downstream
- Upstream Changes Discovered in Downstream
- Hidden Changes Released to Downstream
- Time to Request Reprocess from Downstream
Basic DPM Work Package
Stock-and-Flow Structure
DPM Study: Take-Home Messages

- Quality has a pervasive impact on time, cost
  - Indirect savings from high-quality work may well outweigh extra direct costs of this quality
- Changes have cascading effects in a project
  - Despite up-front costs of rework, many times preferable
- Fast-tracking experiences “double jeopardy”
  - Greater likelihood of changes
  - Greater schedule sensitivity to changes
<table>
<thead>
<tr>
<th>Process simulations <strong>generally</strong></th>
<th>System dynamics simulations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proceed “bottom up”</td>
<td>Proceed “top down”</td>
</tr>
<tr>
<td>- Detailed simulation of activity processes</td>
<td>- Try to capture entire system of major factors</td>
</tr>
<tr>
<td>For emergent statistics, time behavior</td>
<td>- Typically do not model particular activities and resources</td>
</tr>
<tr>
<td>Investigate particular component of interaction on project (but can model entire project)</td>
<td>For emergent time behavior</td>
</tr>
<tr>
<td>Based around discrete event simulation</td>
<td>Include soft factors</td>
</tr>
<tr>
<td>do not include “soft factors” (Morale, fatigue…)</td>
<td>- Rough estimates if necessary</td>
</tr>
<tr>
<td>Generally do not model decision rules</td>
<td>Based around ODE/SDE</td>
</tr>
<tr>
<td>Try to capture decision rules</td>
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</tr>
<tr>
<td>Strive for transparency</td>
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</tr>
<tr>
<td>Seek to use model to capture institutional knowledge for project learning</td>
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</tr>
</tbody>
</table>
Important Distinctions

- Distinction 1: Precision vs. Accuracy
- Distinction 2: Power of modeling vs. ease of creating useful model
- Distinction 3: General modeling vs. for a specific purpose
- Distinction 4: Modeling for prediction vs. for understanding
TP4 Presentations

- TP4 involves both a
  - Written report
  - Final Presentations (20-25 minutes)
- The written report will be due May 10 for everybody
- The presentations will be held on either
  - May 10
  - May 12
Grading

- Rework for those who wish to do extra work on PSet 3
- Extra credit Assignment based on “Skycraper”
  - Watch 5 hour-long videos
    - Proposed time:
      - Tuesday, April 27 5-8
      - Friday, April 30 5-7
    - Write a 5-page analysis