System and Change Dynamics

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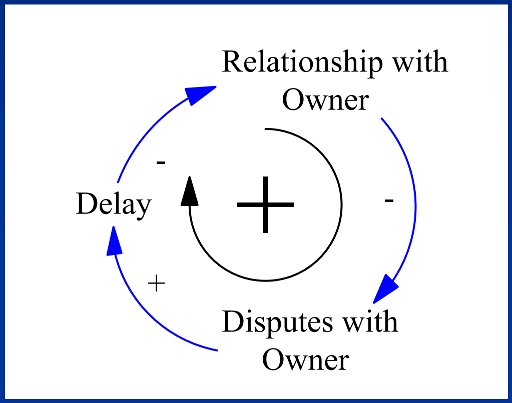
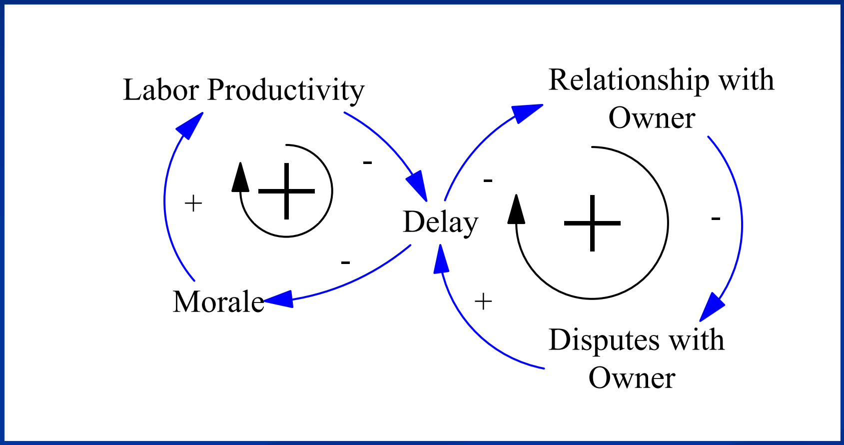
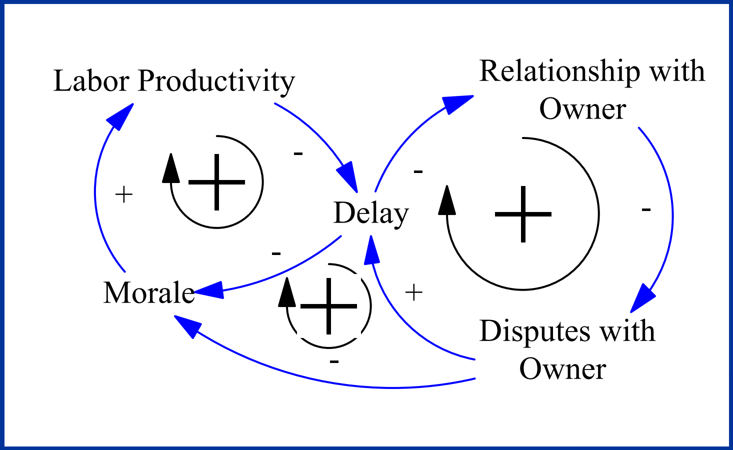
Systems Thinking and Project Management

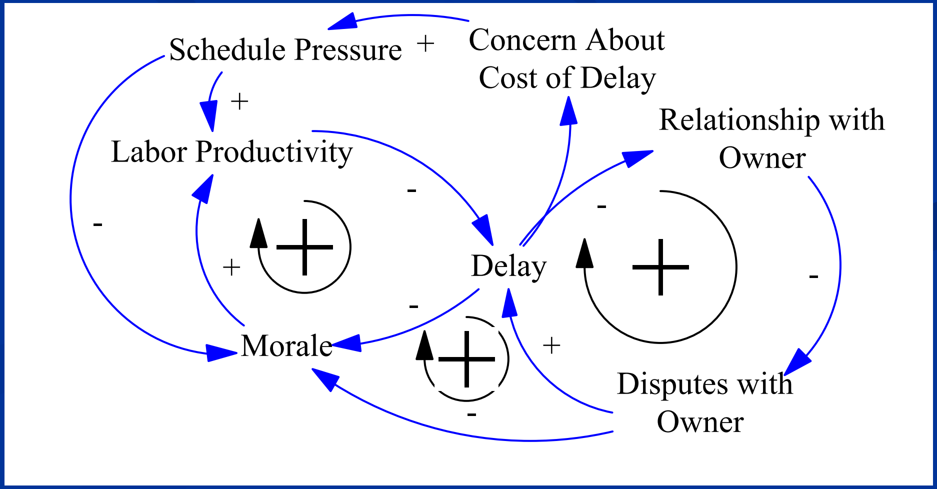
- Primary critique: Traditional methods too
  - Fragmented
  - Restrictive in assumptions
  - Local in attention to implications of changes
  - Hesitant regarding representation of "soft" factors
  - Too dependent on people link components
  - Too willing to ignore important "side effects"
- Seen as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

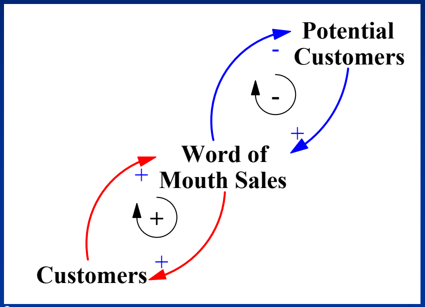
- Represents system as coupled series of ordinary differential equations (ODEs)
  - Standard state-equation formulation
  - Continuous time formulation
  - Stochastic components permissible (special handling)
  - Analytic solutions not possible: Numerically integrate
- Graphical representation for problem focus
  - State equations as stocks
  - Components of differentials as follows
  - Intermediate computations as auxiliaries, table functions, etc.

How a SD Model is Created

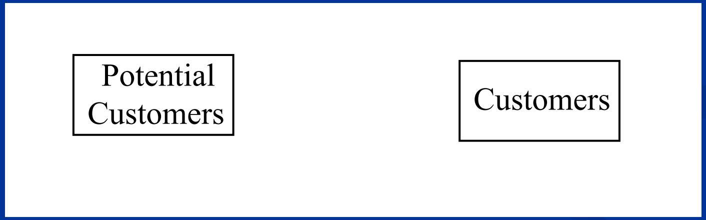
- Conceptualize system using causal loop diagram
- Convert CLD to "stock & flow" *structure*
  - State variables (accumulations) as stocks
  - Changes to state variables as flows
    - All *change* in system state occurs through *flows*
  - All loops include at least one stock
  - Intermediate calculations, 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

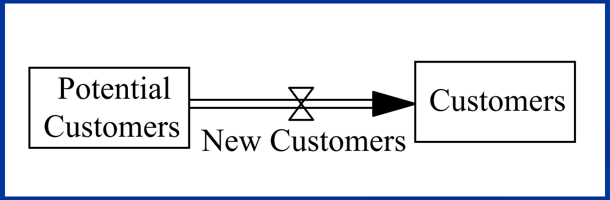
- Step 1: Map out Causal Loops



- Step 2: Identify state variables of interest

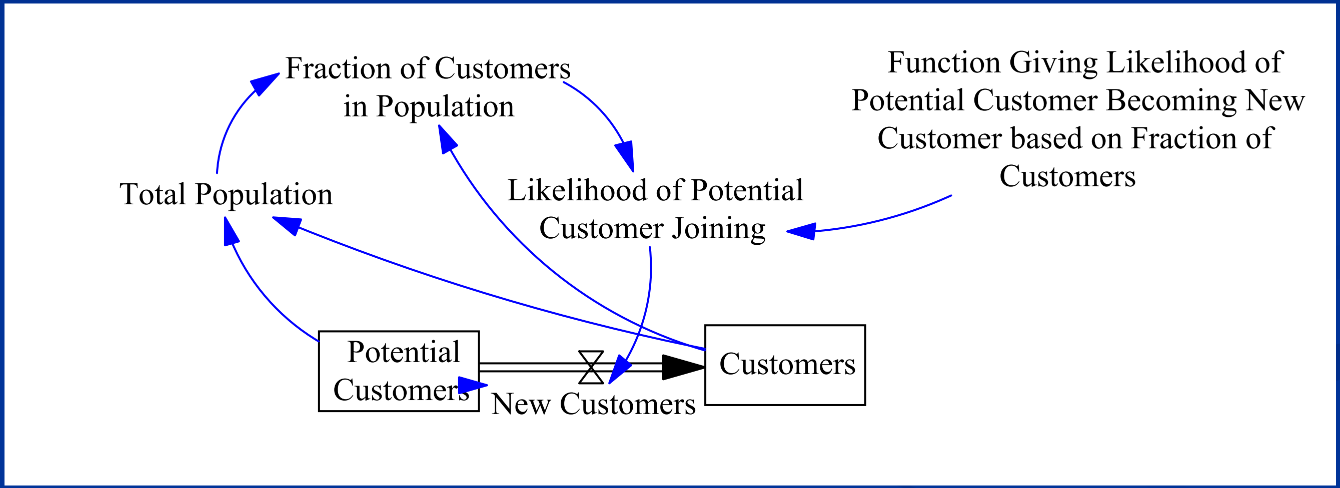


- Step 3: Identify flows of interest



Example Creation of a System Dynamics Model

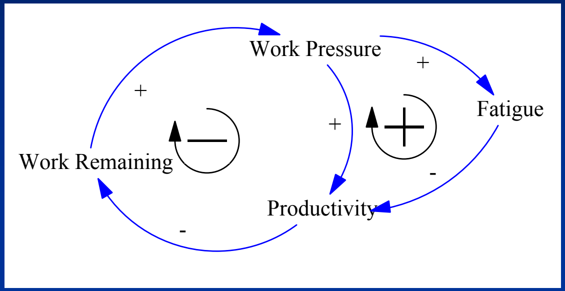
- Step 4: Define Supporting Variables



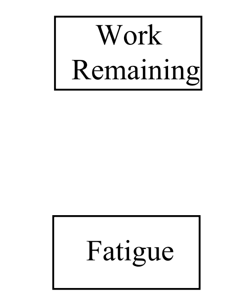
- Insert equations to describe linkages
  - E.g.
    - Total Population = Customers+Potential Customers
    - Fraction of Customers in Population= Customers/Total Population

Example Creation of a System Dynamics Model II

- Step 1: Map out Causal Loops



- Step 2: Identify state variables of interest



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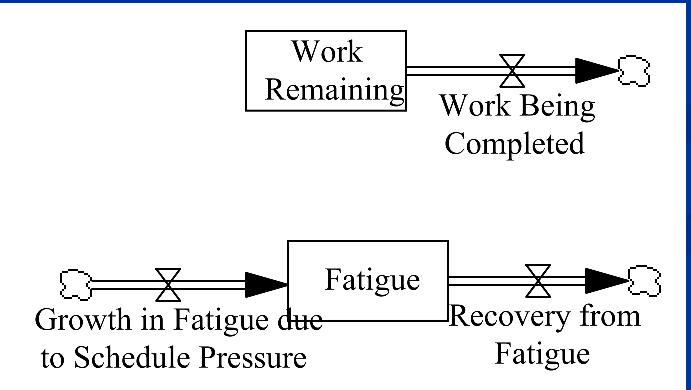
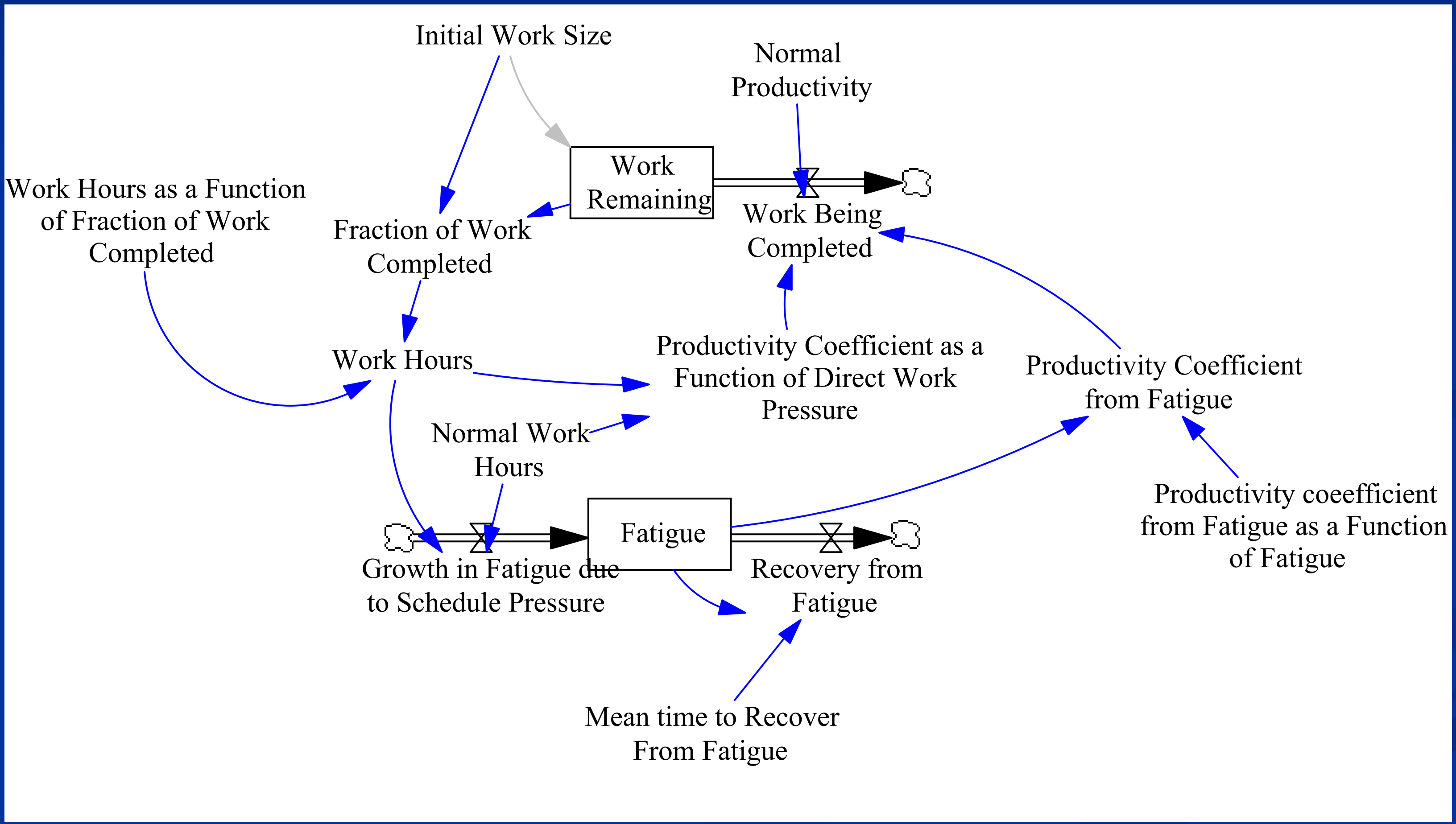


Example Creation of a System Dynamics Model



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

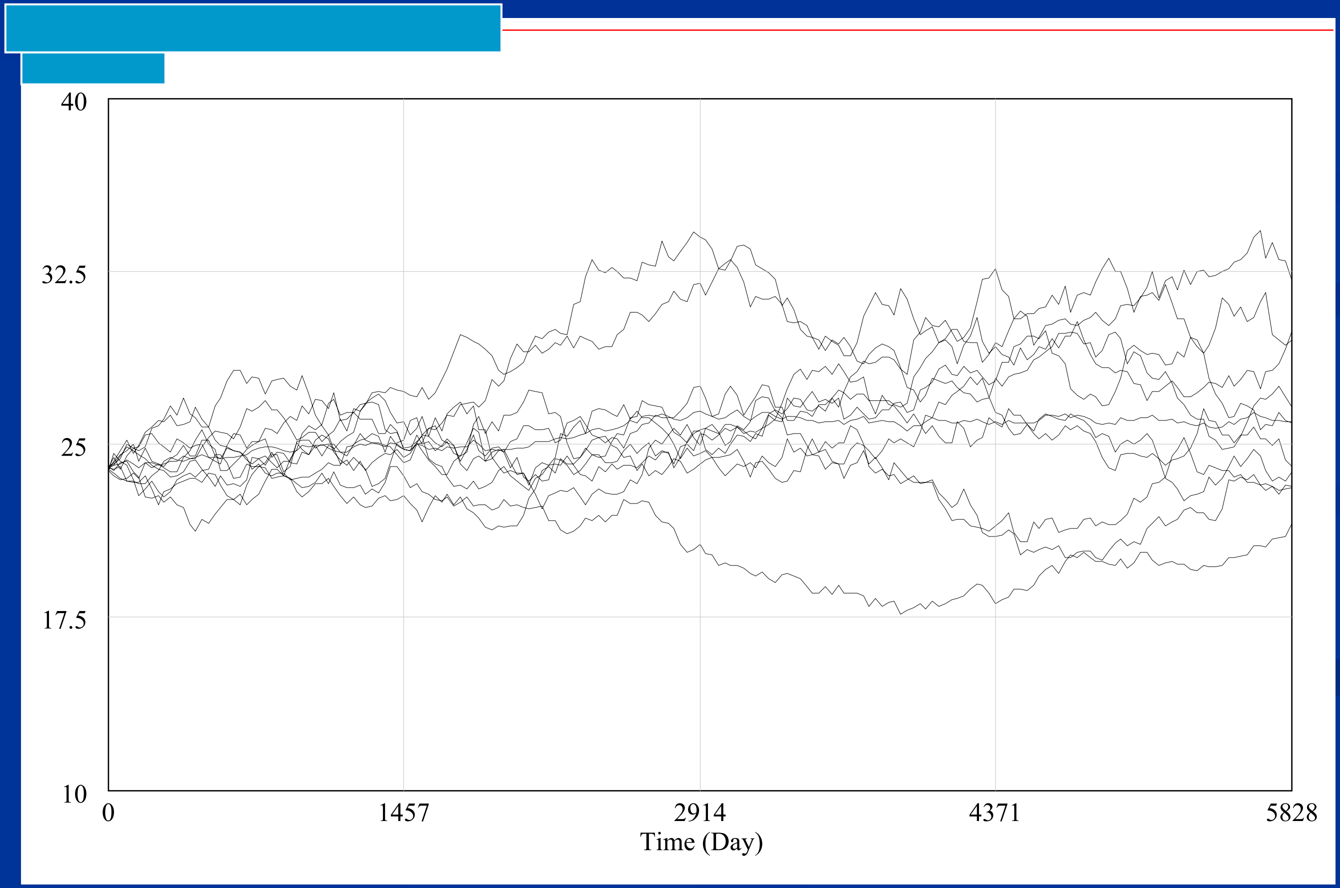
- Typical first step: Assume some "baseline" scenario
  - Just point of reference – not particularly privileged
- "Policy" scenario analysis
  - Change "policy parameters" (e.g. hiring policy, fraction change vs. rework, etc.) and look at results
- Policy robustness to uncertainty
  - For different policy 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

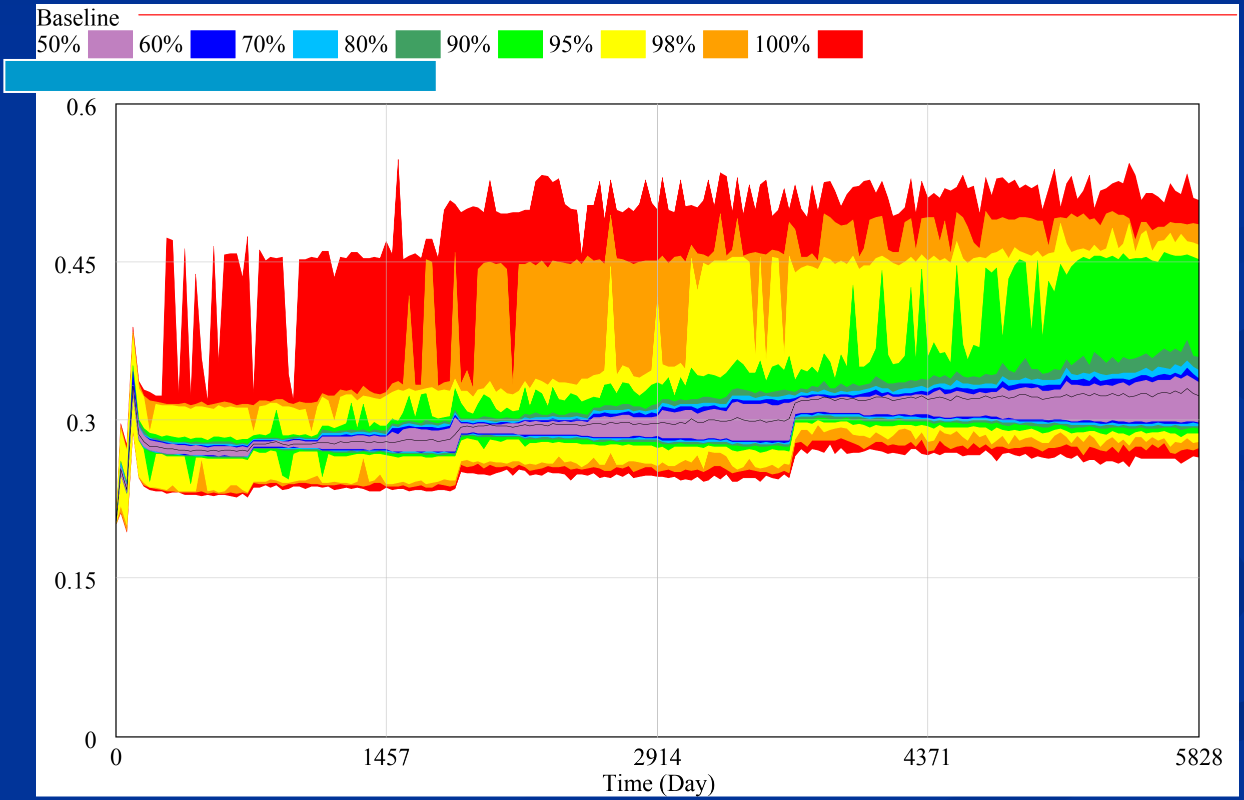
Stochastic Process Monte Carlo

- Essentially numerically solving stochastic differential equation



Monte Carlo Output

- Empirical fractiles shown with color coding



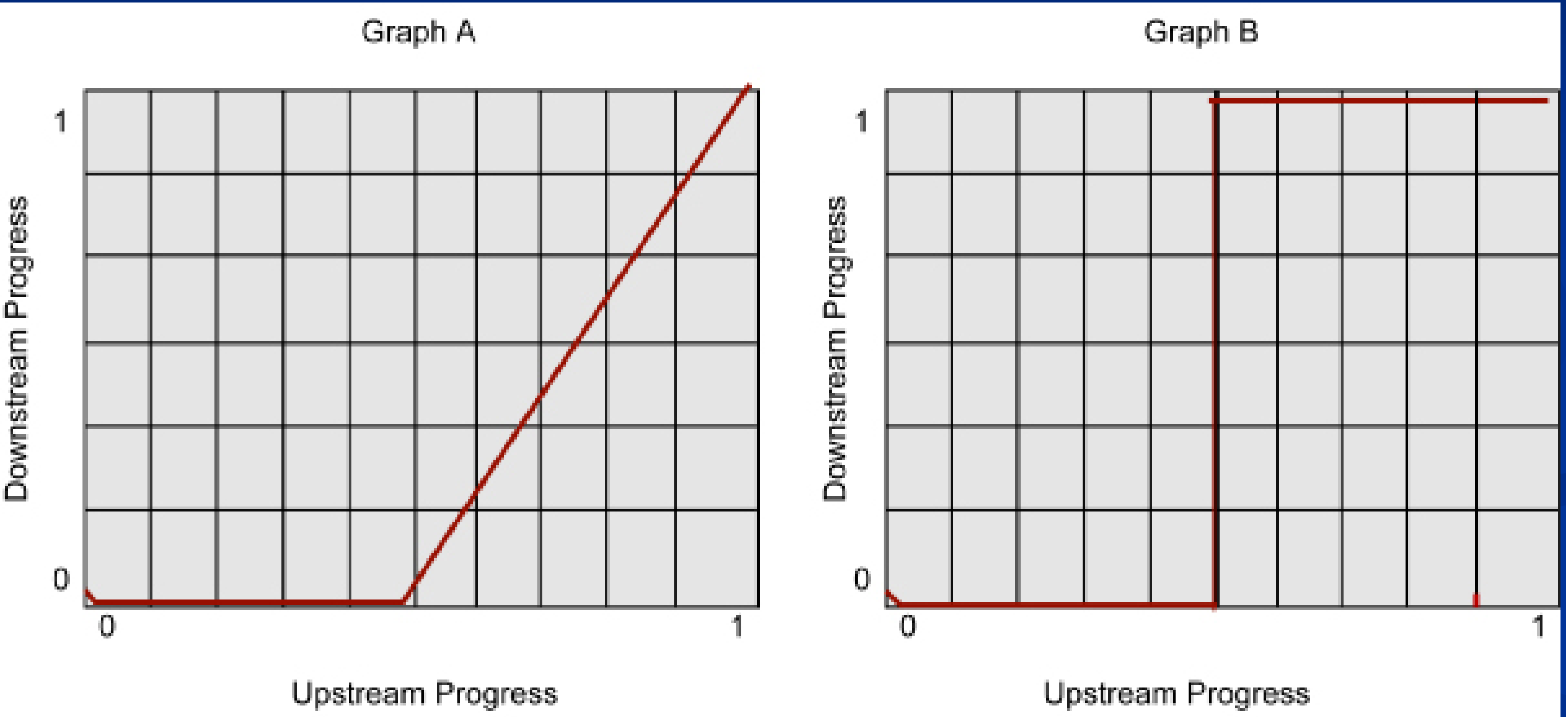
Coexistence…or Integration?

- 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

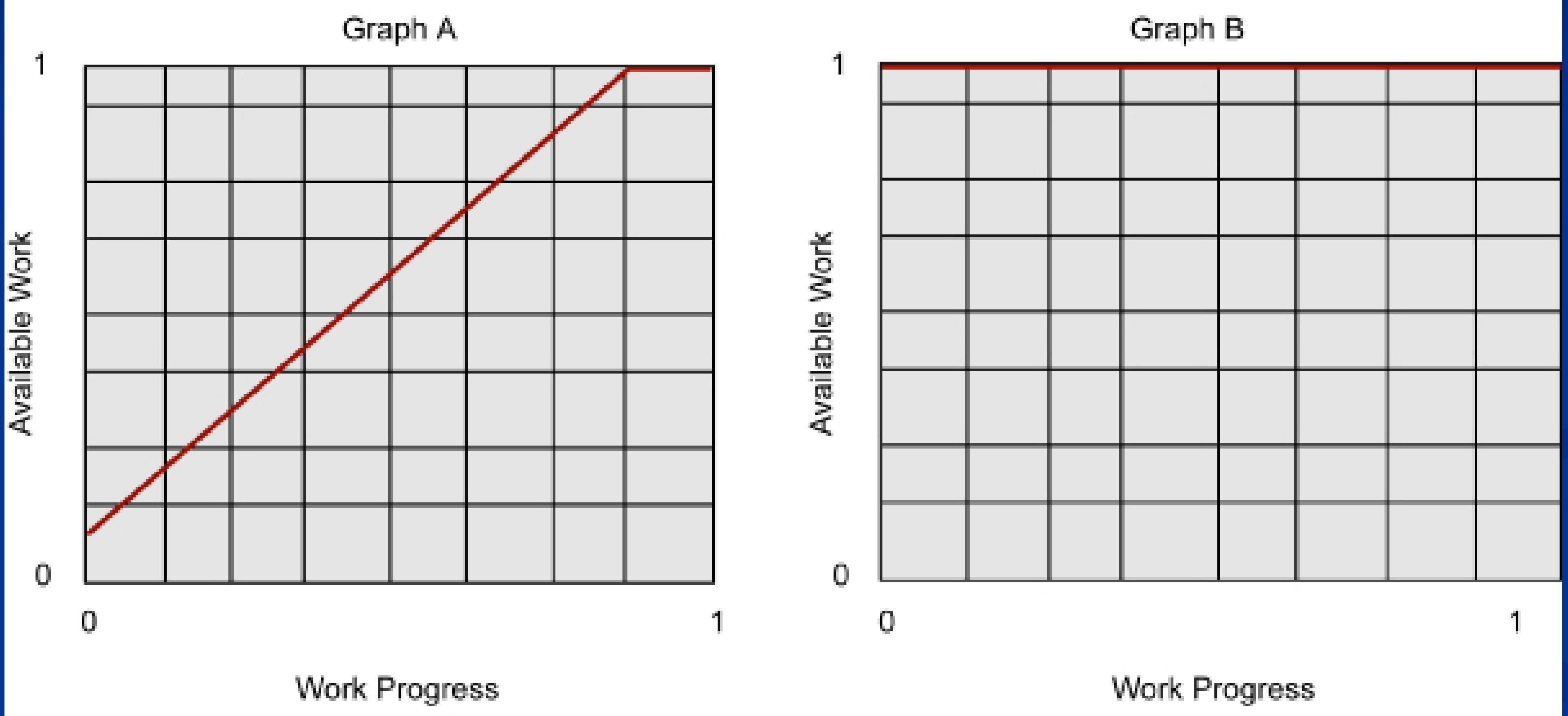


Examples of External Dependency [adopted from Ford and Sterman (1997)]

Example: Plumbing & Electrical Roughing and Drywall

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

Internal Dependencies



Examples of Internal Dependency [adopted from Ford and Sterman (1997)]

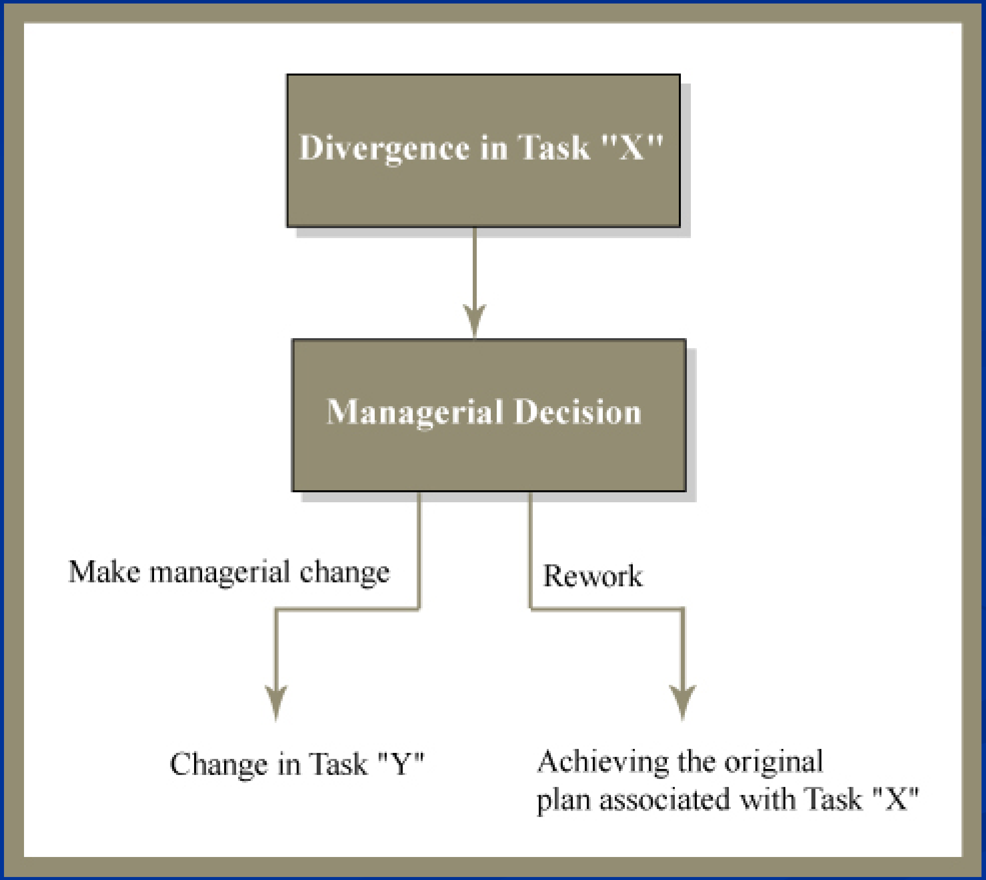
Example: Subsequent Floors

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



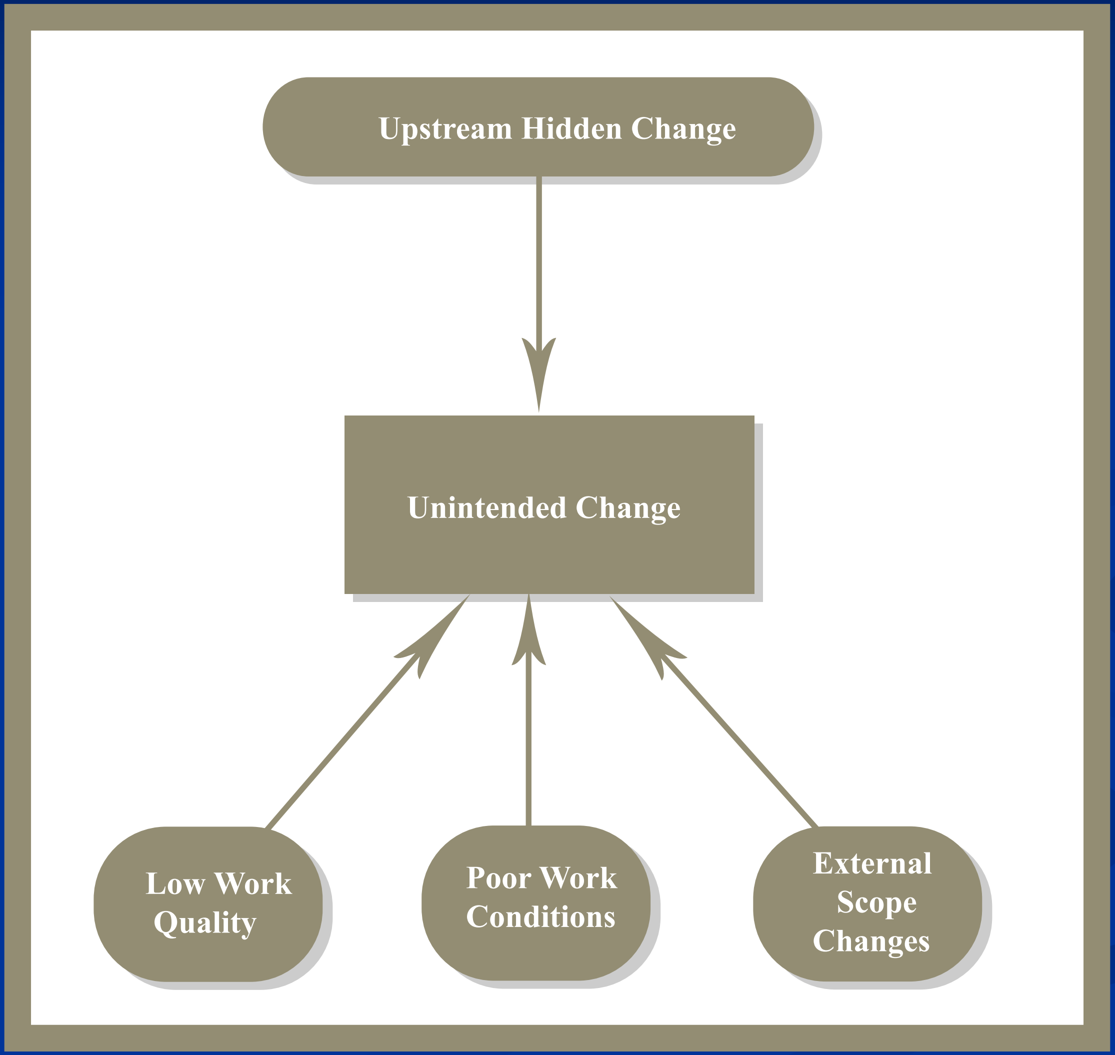
Rework

- 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



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

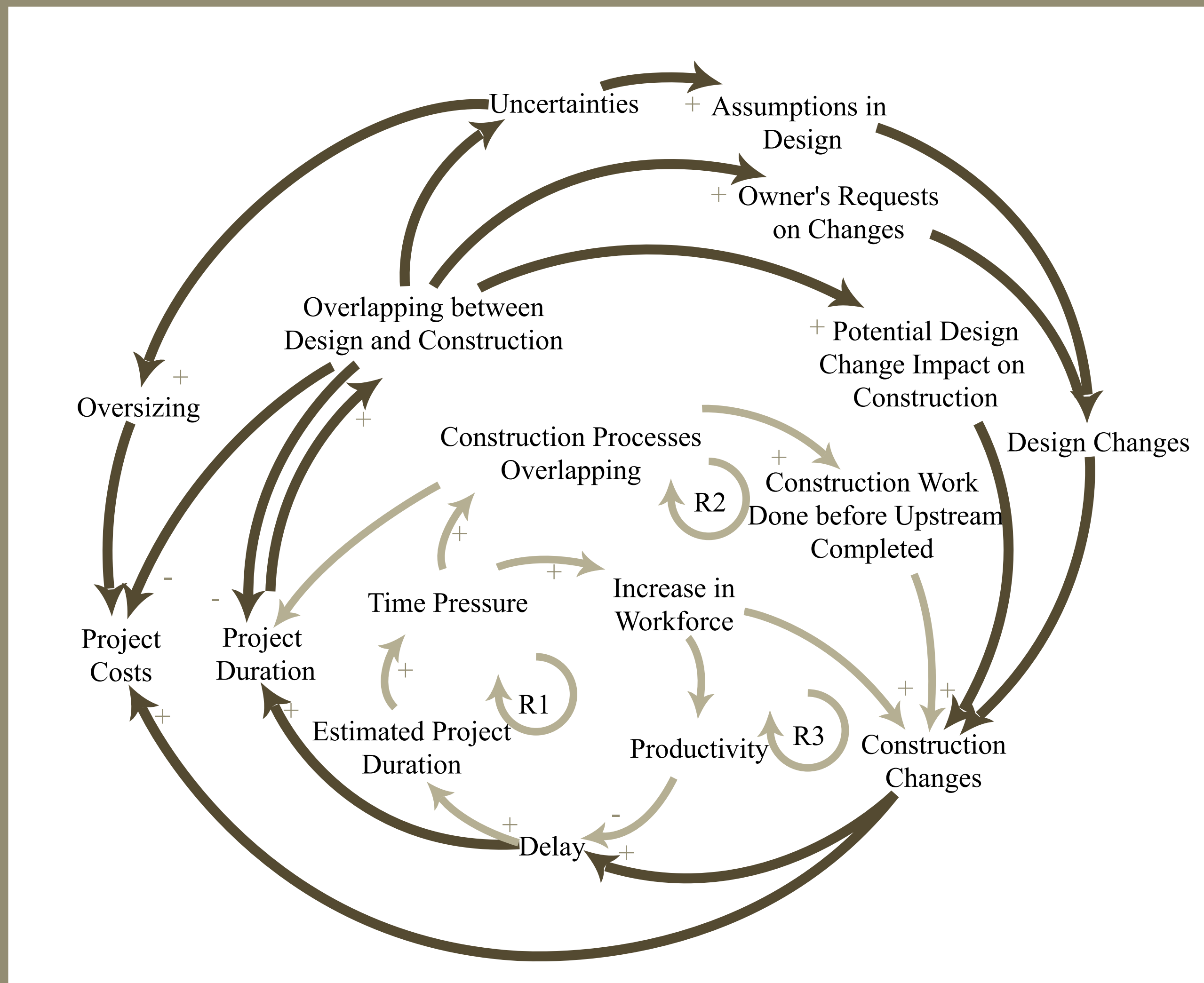
Example of Change Propagation

- 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 o f building
  - Delays can affect customer relations, idle resources, interfere with other A/E activities, increase pressure…

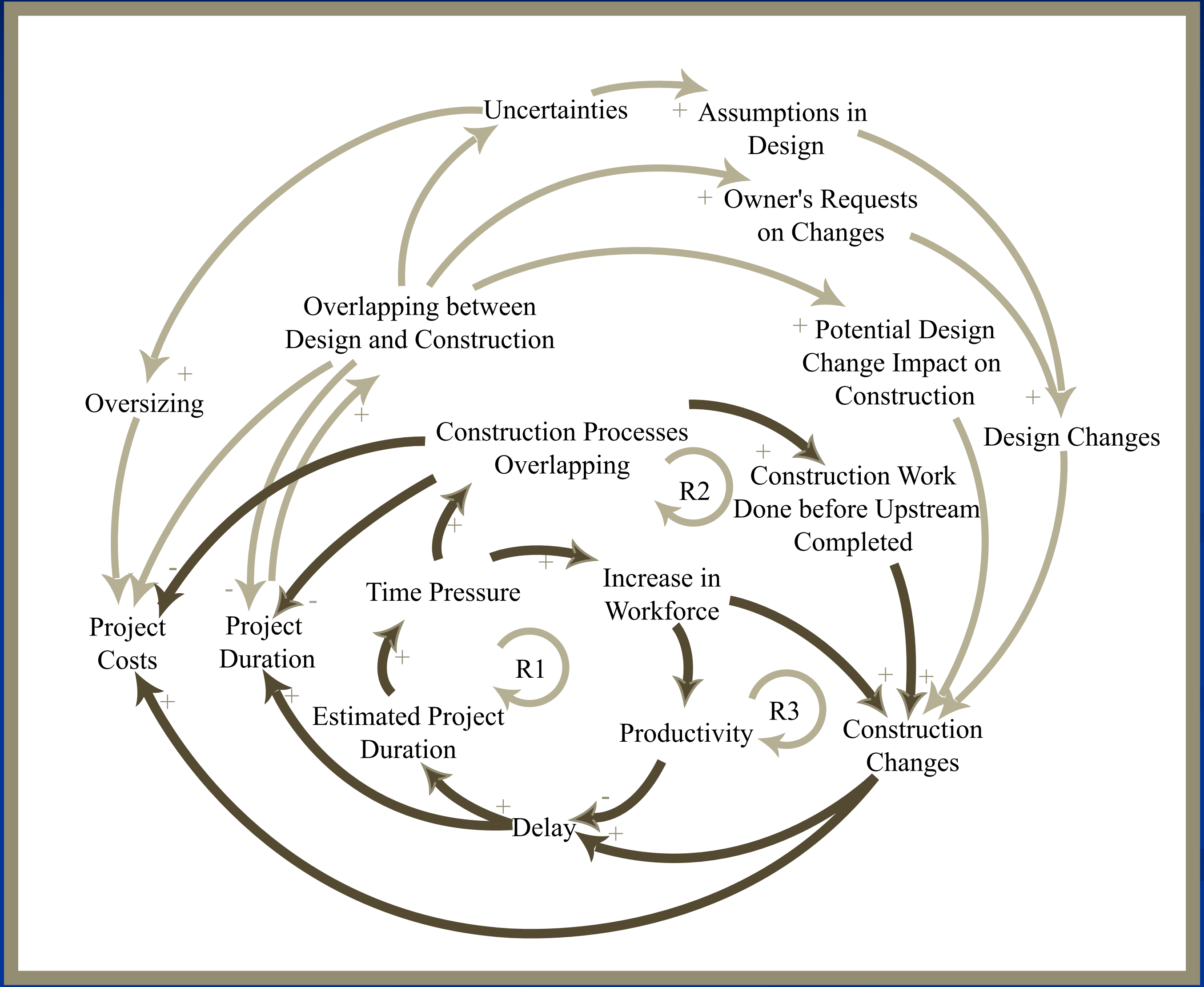
Big Picture: Role of Flexibility

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

Design Overlap Feedbacks



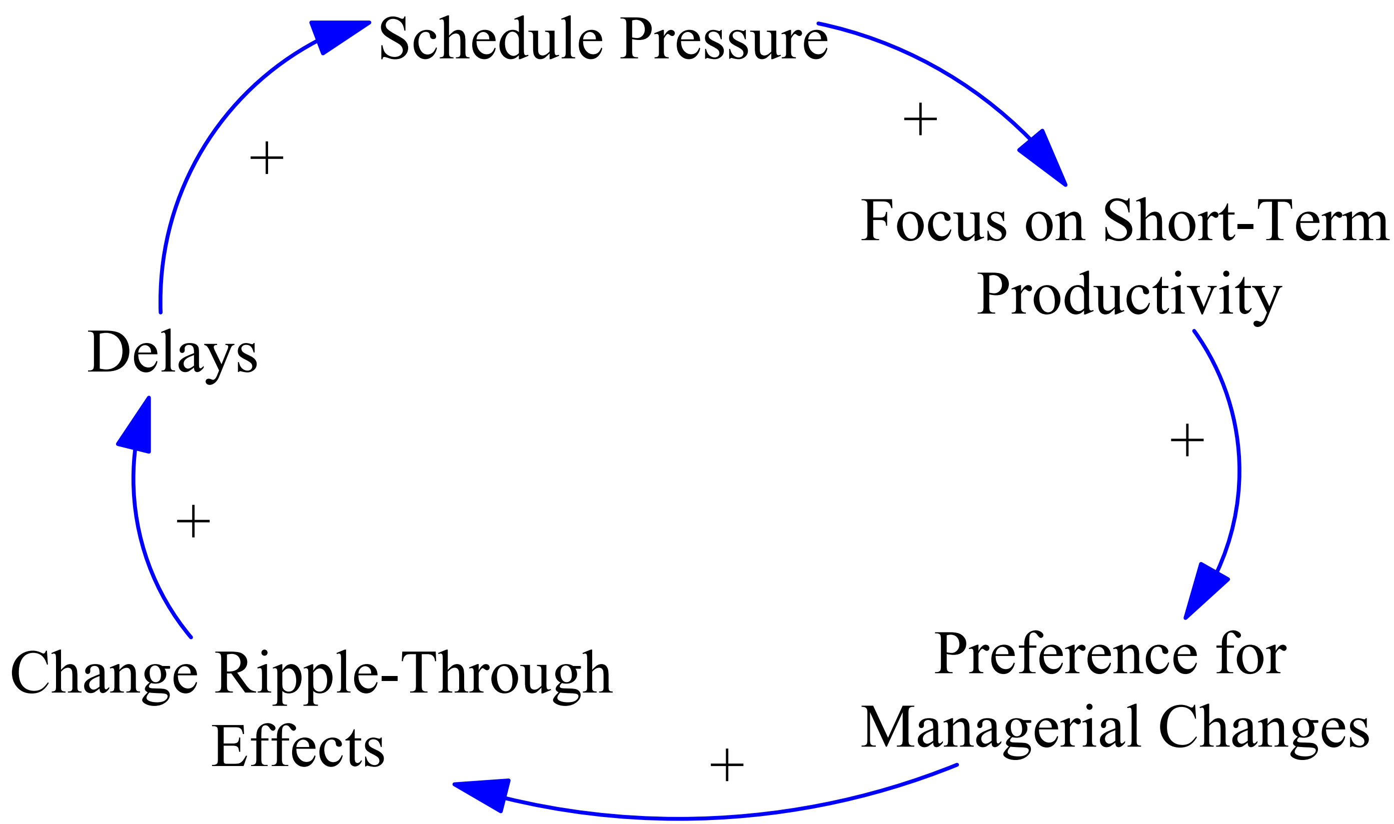
Construction Overlap Feedbacks



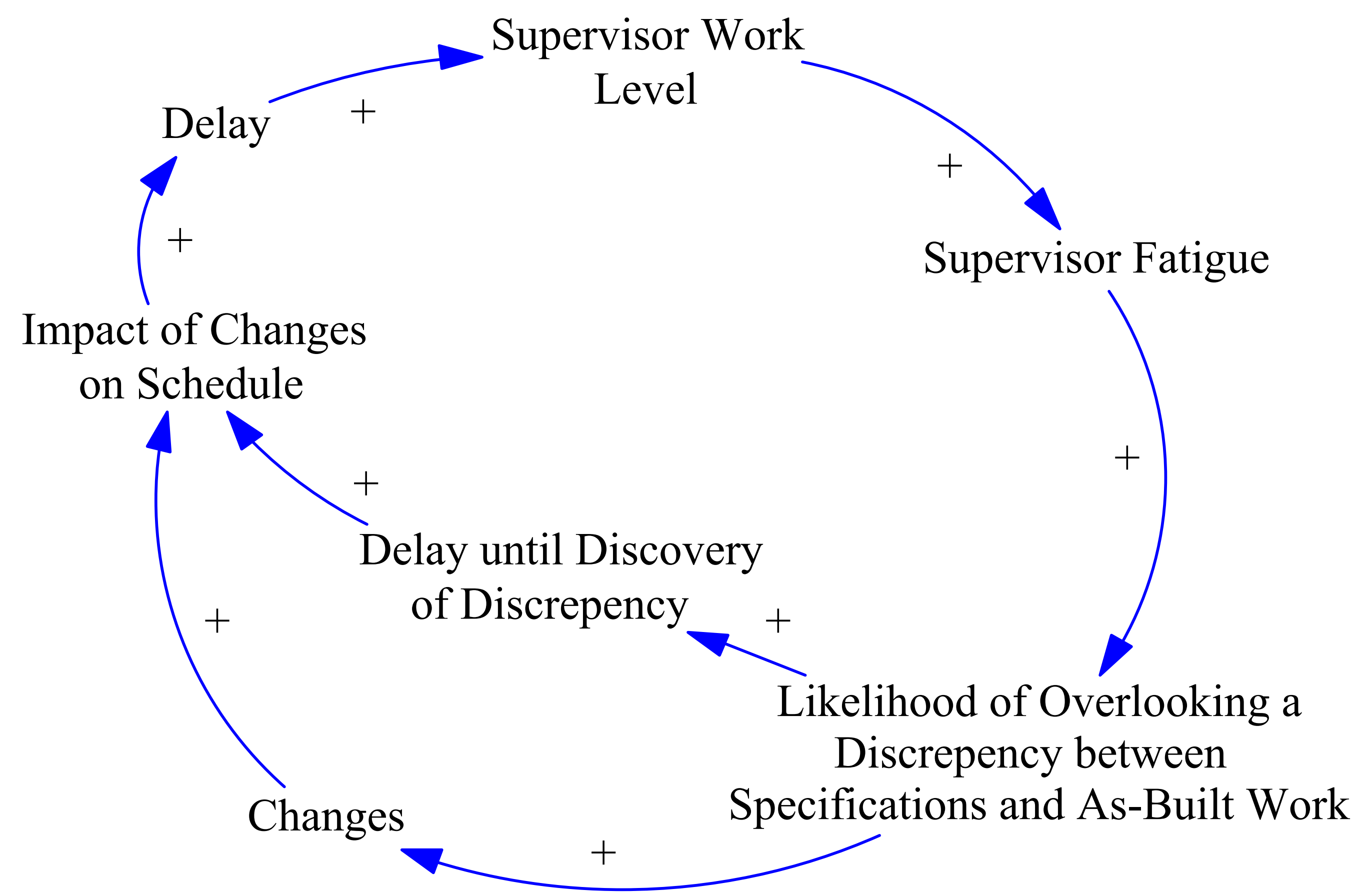
Big Picture: Fast-Tracking and Overlapping of Activities Has Multiple Risks

- 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

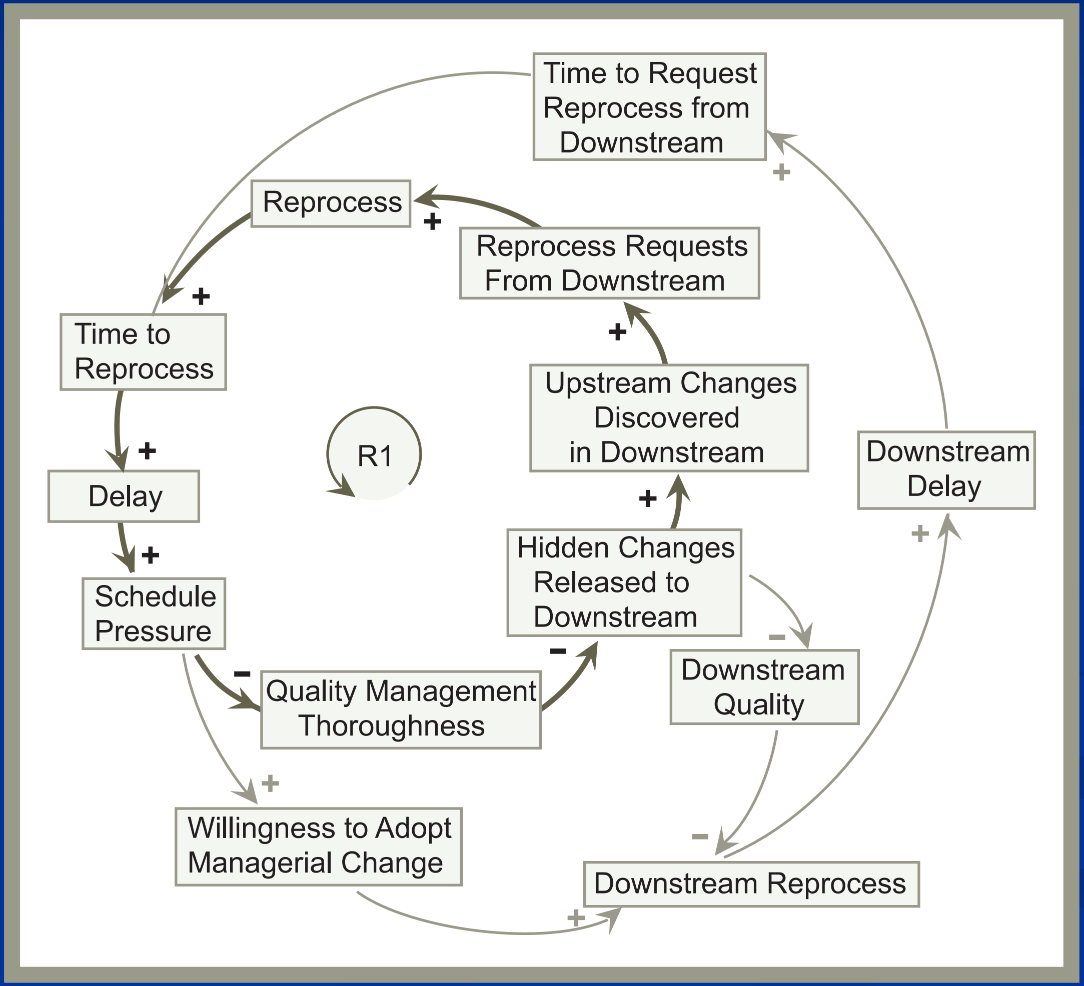
Additional Feedbacks 1



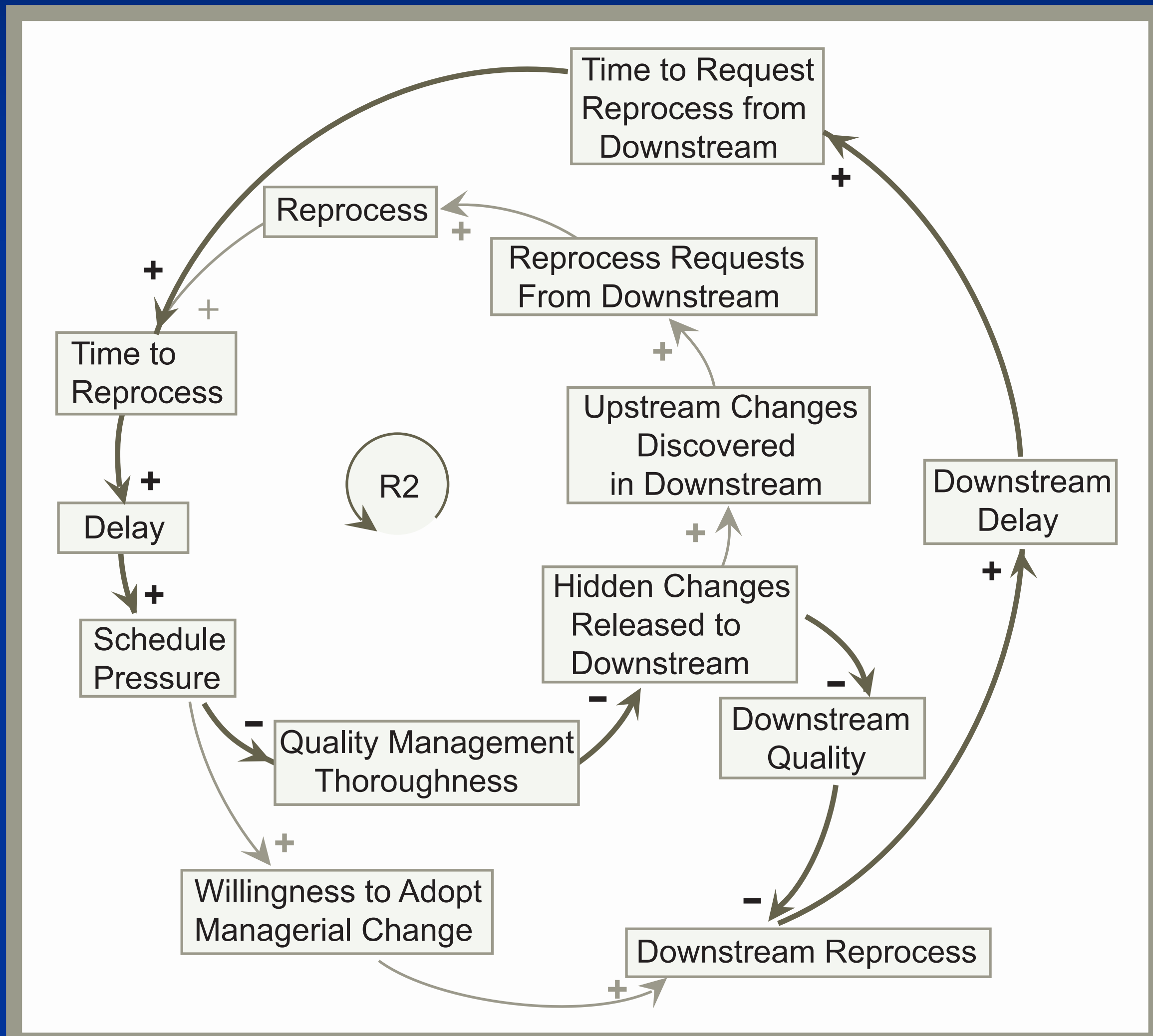
Additional Feedbacks II



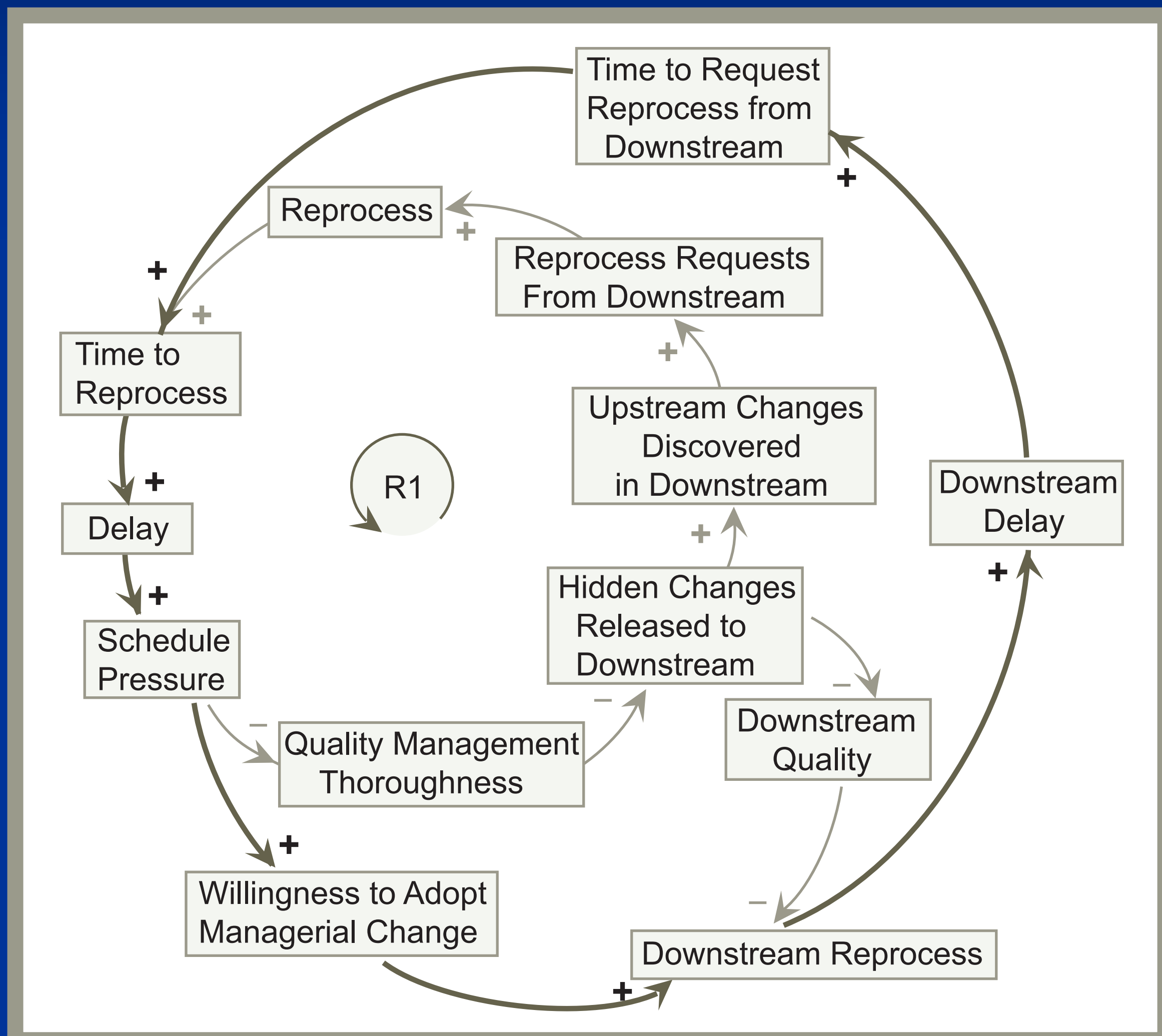
Change Process Loop 1: DS Pre-check Identifies Divergence



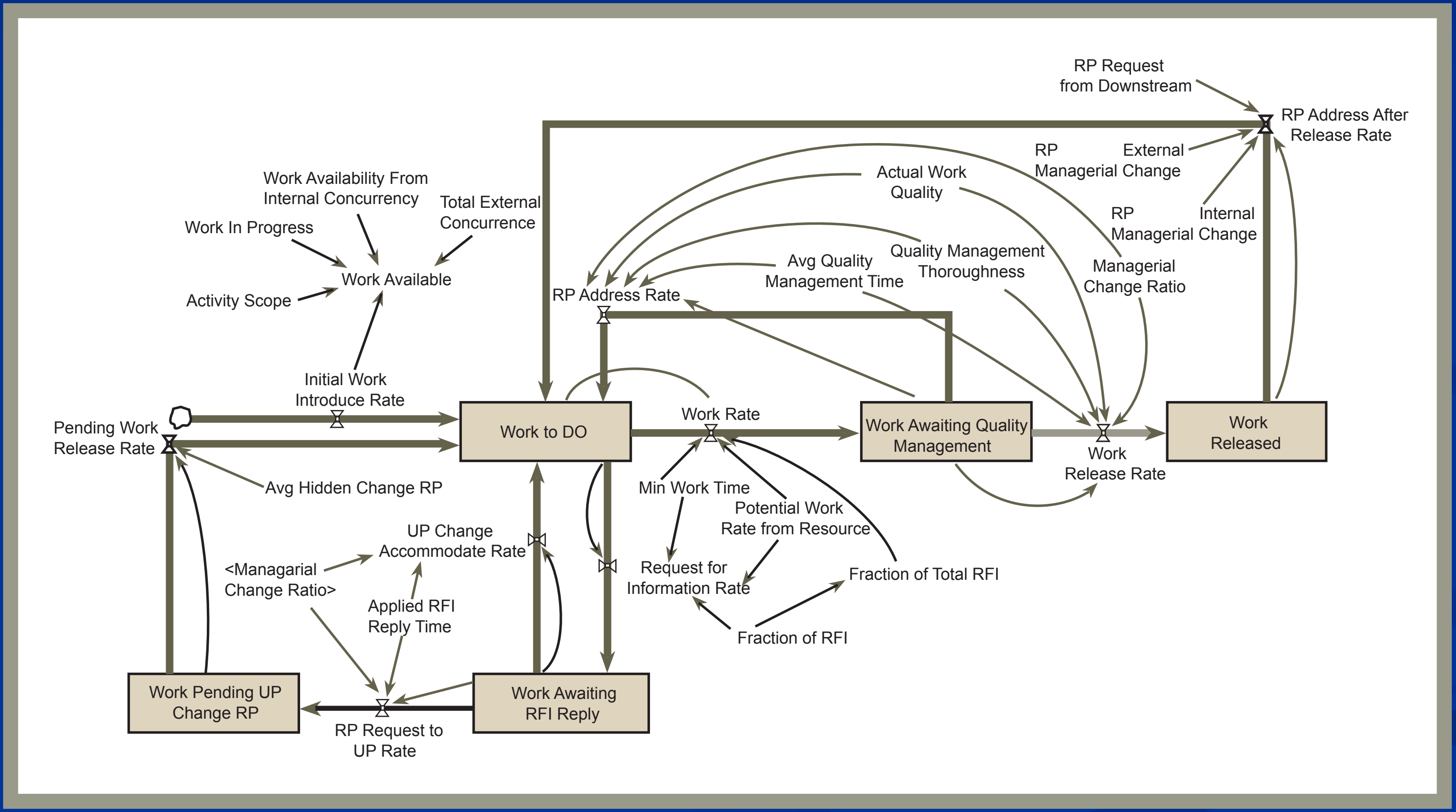
Change Process Loop 2: Divergence Discovered During DS Work



Change Process Loop 3: Specification Change Adopted



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 preferaable
- Fast-tracking experiences "double jeopardy"
  - Greater likelihood of changes
  - Greater schedule sensitivity to changes

System Dynamics Simulation vs Process Simulation

- Process simulations **generally**
  - Proceed "bottom up"
    - Detailed simulation of activity processes
  - For emergent statistics, time behavior
  - Investigate particular component of interaction on project (but can model entire project)
  - Based around discrete event simulation
  - do not include "soft factors" (Morale,fatigue…)
  - Generally do not model decision rules

- System dynamics simulations
  - Proceed "top down"
    - Try to capture entire system of major factors
    - Typically do not model particular activities and resources
  - For emergent time behavior
  - Include soft factors
    - Rough estimates if necessary
  - Based around ODE/SDE
  - Try to capture decision rules
  - Strive for transparency
    - Seek to use model to capture institutional knowledge for project learning

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