Problem Diagnosis & Introduction to Project Dynamics

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Topics

- Problem Diagnosis
  - Pareto Analysis
  - Fishbone Diagram
  - Scatterplots
- Systems Thinking and System Dynamics
  - Causal Loop Diagrams
  - System Dynamics

Insights into Causes of Problems

- Discussed Last Time : Exploratory Analysis
- Pareto Analysis
- Fishbone Diagram
- Scatter Diagram
- Causal Loop Diagram

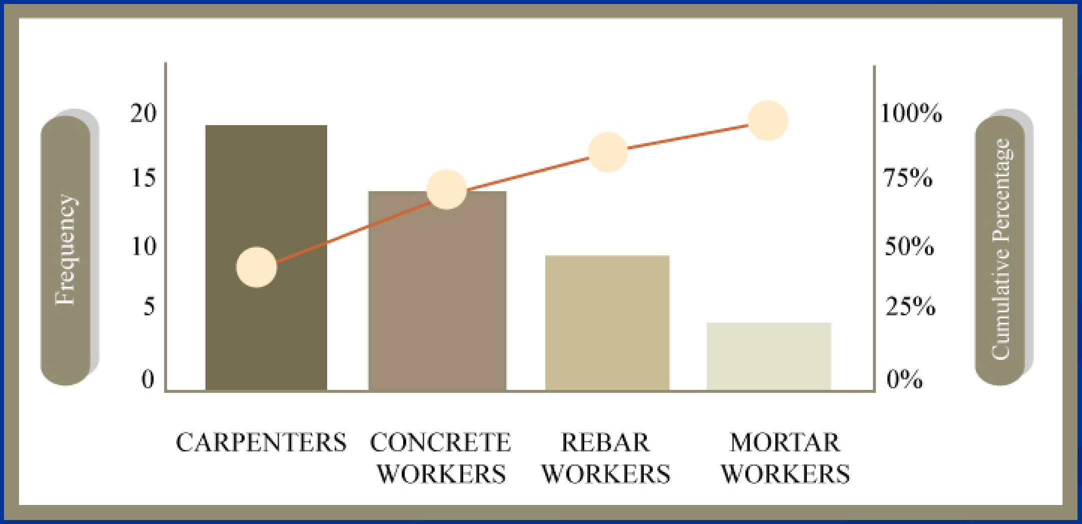
Pareto Analysis

- Correctly addressing a small portion of project components can provide control over the remaining project components.
- Help identify the contributors to given types of performance, mostly cost and quality performance.
- Group A: a small portion of the major cost components that account for a significant portion of the total cost
- Group B: all cost component other than Group A and C components
- Group C: a large portion of the minor cost components that account for a trivial portion of the total cost

Pareto Analysis

- Example: Drivers of Quality Problems in Building Construction

Workers	Frequency
Rebar workers	10
Concrete workers	15
Carpenters	20
Mortar workers	5



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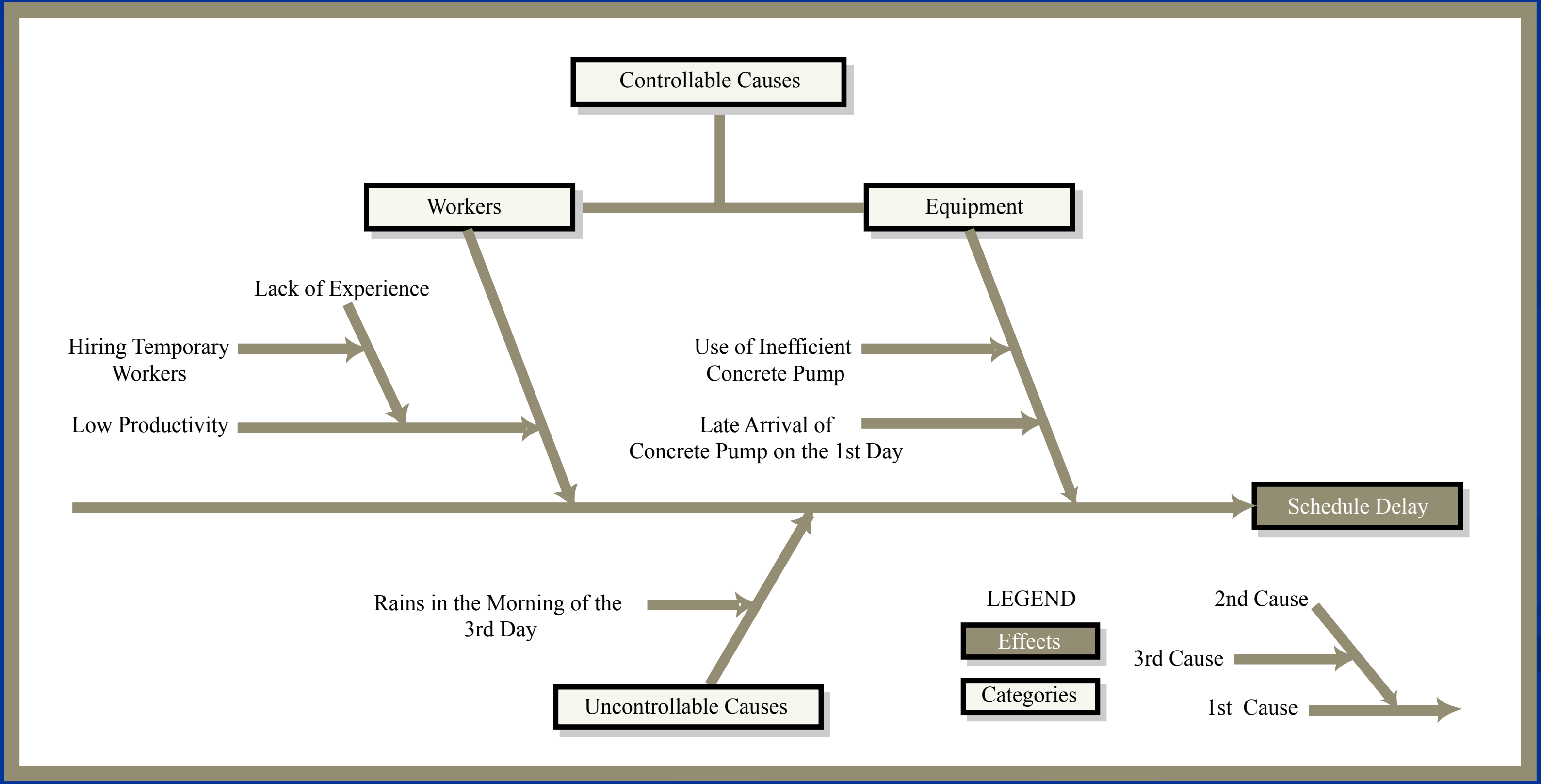
Fishbone ("Cause and Effect") Diagram

- Help identify the drivers of given performance problems, by providing a format with which managers can easily understand <u>cause and effect</u> relationships.
- The causes for a given performance problem are analyzed by initially defining the problem and then channelling possible causal relations on the defined problem into predetermined (proj.-specfic)categories
- Subcauses shown as progressively refined branches

Fishbone Diagram

- **Example: Delay in concrete pouring**



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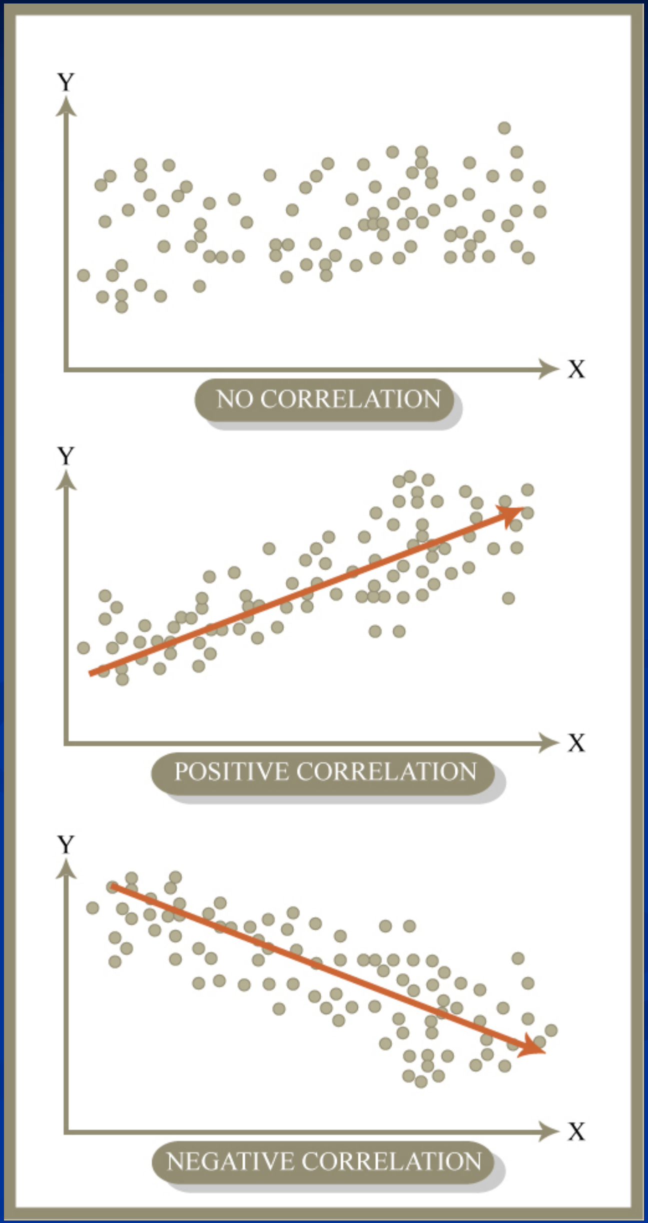
Scatter Diagram

- Help predict the trend of future performance by showing the *correlation* between different variables.
- The data set used in a scatter diagram consists of an independent variable and a dependent variable
- Representing the independent variable on the horizontal axis and the dependent variable on the vertical axis, a scatter diagram can plot the correlation between two variables

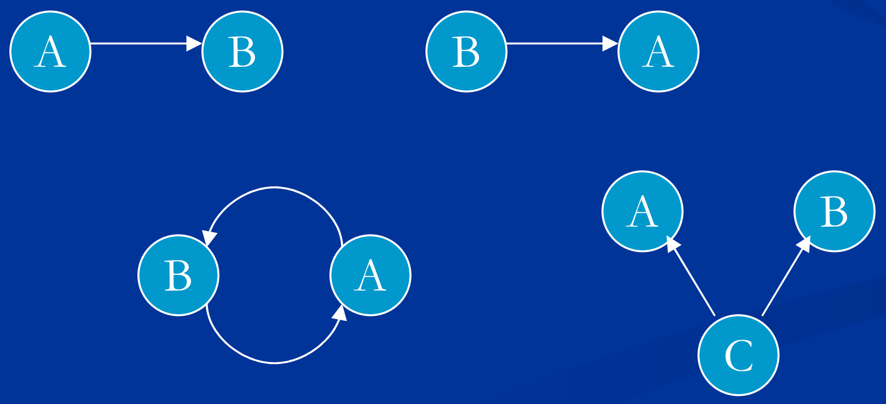
Scatter Diagram

- Different types of correlations



Scatter Diagram Disadvantages

- *Correlation* does not necessitate a *causal linkage*
- Many potential directions of causal chains could explain a given correlation
  - E.g. suppose A is correlated with B
  - Possible Causal linkages



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Systems Thinking and System Dynamics

- Systems thinking focuses on
  - Conceptualizing problems in broader context
  - Emphasizes interconnections rather than reductionist reasoning
  - Internal rather than internal factors
  - Feedback structure of system as primary determinant of behavior
- Common manifestations
  - Qualitative: Causal loop diagrams
  - Quantitative: System dynamics

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)

Critique of Fragmentation

- Consider traditional discrete methods
  - CPM, Resource algs, time/cost tradeoffs, productivity considerations, manual check of global
  - Activities analyzed in isolation (local impact of delaying activity or extending activity duration)
- Productivities, resource use, quality, cost all linked
  - Delay/extension of activity influences resources, morale, productivity, etc.
    - Takes people from other activities, idles others
    - May affect customer relations, allocation of labor to project
    - Makes overtime, concurrency more likely ($\Rightarrow$ lower quality)
    - Requires reconsidering subcontractor, material procurement
  - Typical schedulers do not think through all implications
- Plans is always changing, being updated

Causal Loop Diagram

- Like fishbone diagram, focus on causation
  - Contrast with *correlation* focus of scatterplot
- More general, expressive than fishbone
  - Cyclic: Focus on capturing *feedback* effects
  - Indicate sign of causal impact (+ vs. –)
  - $x \longrightarrow^{+} y$ indicates $\frac{\partial y}{\partial x} > 0$
  - $x \longrightarrow^{-} y$ indicates $\frac{\partial y}{\partial x} < 0$

Causal Loop Diagram

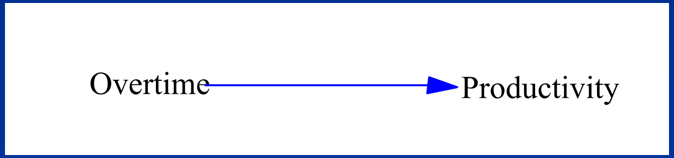
- An arrow with a positive sign (+): “all else remaining equal, an increase (decrease) in the first variable increases (decreases) the second variable above (below) what it would otherwise have been.”
- An arrow with a negative sign (-): “all else remaining equal, an increase (decrease) in the first variable decreases (increases) the second variable below (above) what it otherwise would have been.”

Reasoning about Link Polarity

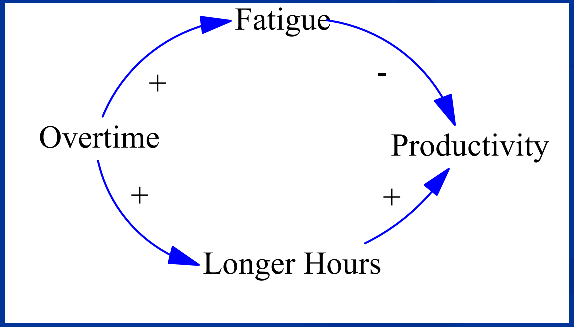
- Easy to get confused regarding link polarity in the context of a causal chain
- Tips for reasoning about link polarity for X→Y
  - Reason about this link in isolation – do not be concerned about links preceding X or following Y
  - Ask "if X were to INCREASE, would Y increase or decrease"?
    - Increase in Y implies "+", Decrease in Y implies "-"
    - If answer is not clear or depends on value of X, need to think about representing several paths between X and Y

Ambiguous Link

- Ambiguous Link: Sometimes +, sometimes -



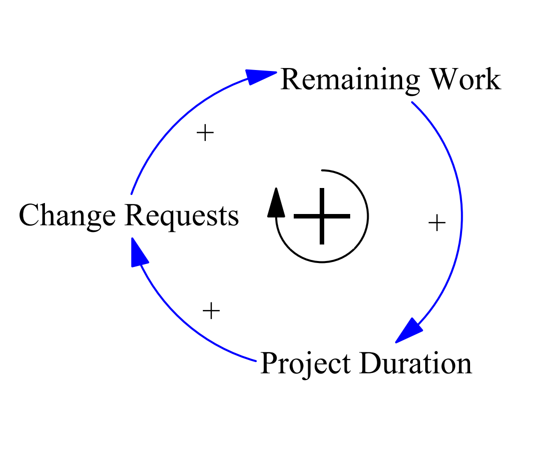
- Replace this by disaggregating causal pathways by showing multiple links

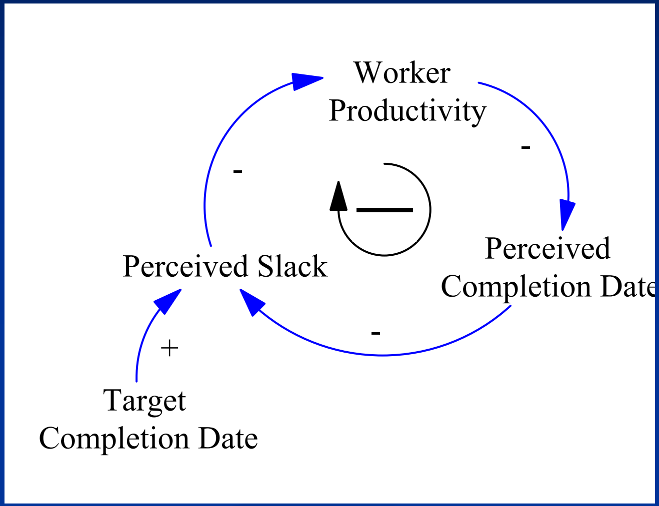


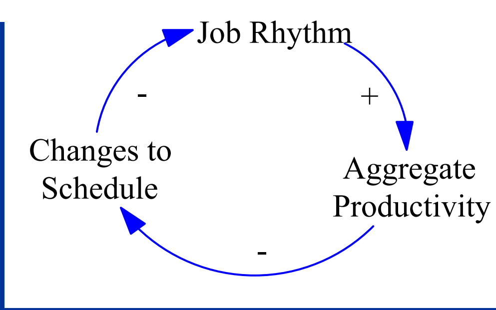
Feedback Loops

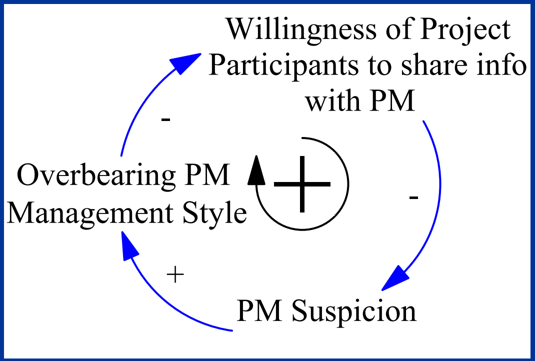
- Loops in a causal loop diagram indicate *feedback* in the system being represented
  - Qualitatively speaking, this indicates that a given change kicks off a set of changes that cascade through other factors so as to either amplify ("reinforce") or damp ("balance") original change
- Loop classification: product of signs in loop
  - Balancing loop: Product of signs negative
  - Reinforcing loop: Product of signs positive

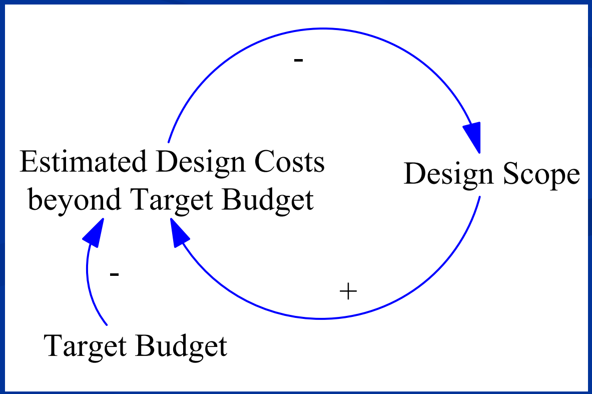
Simple Causal Loops



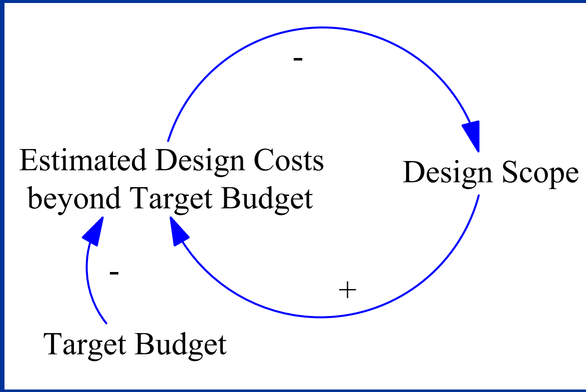


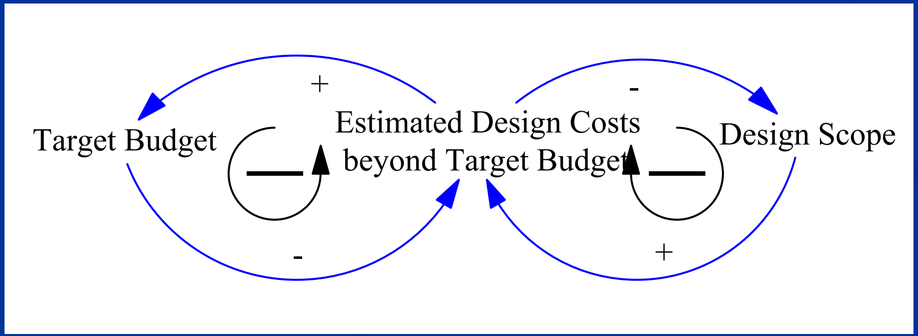




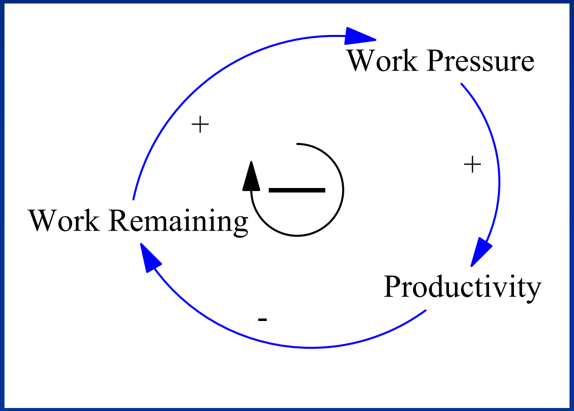


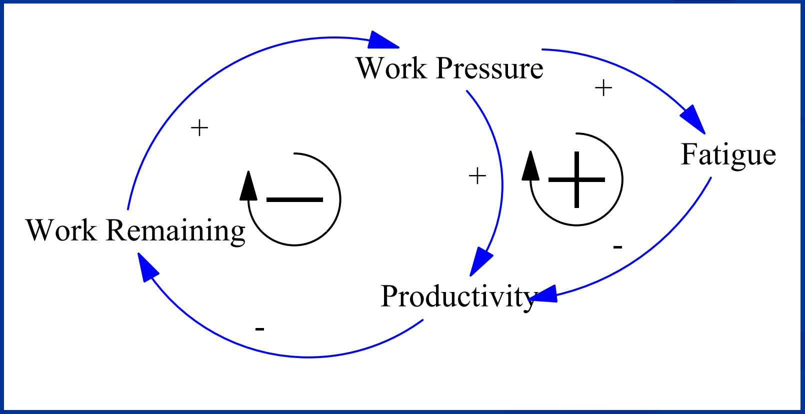
Elaborating Causal Loops 1



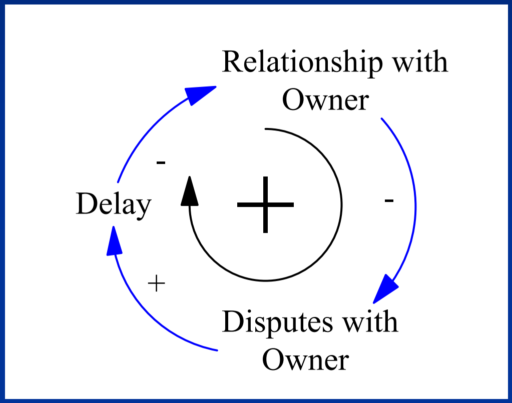


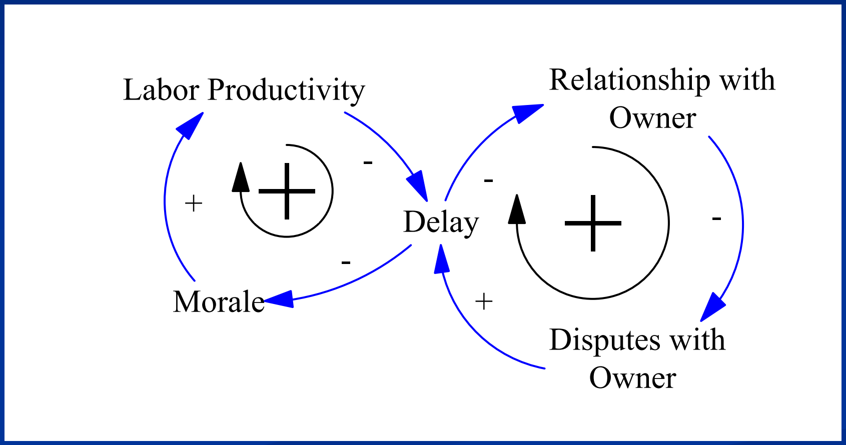
Elaborating Causal Loops 2

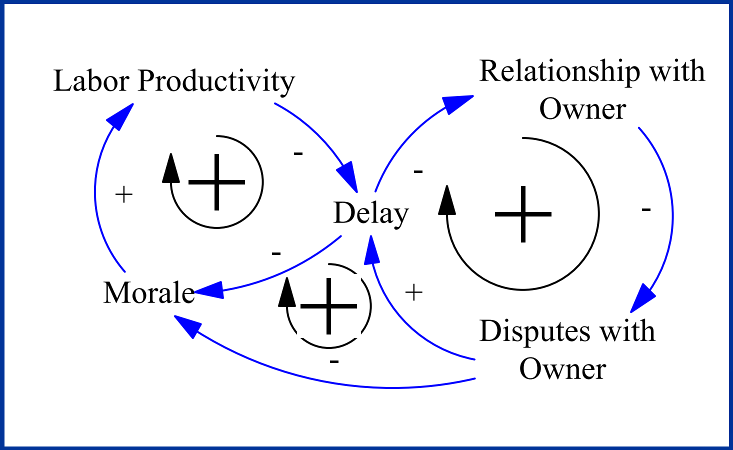


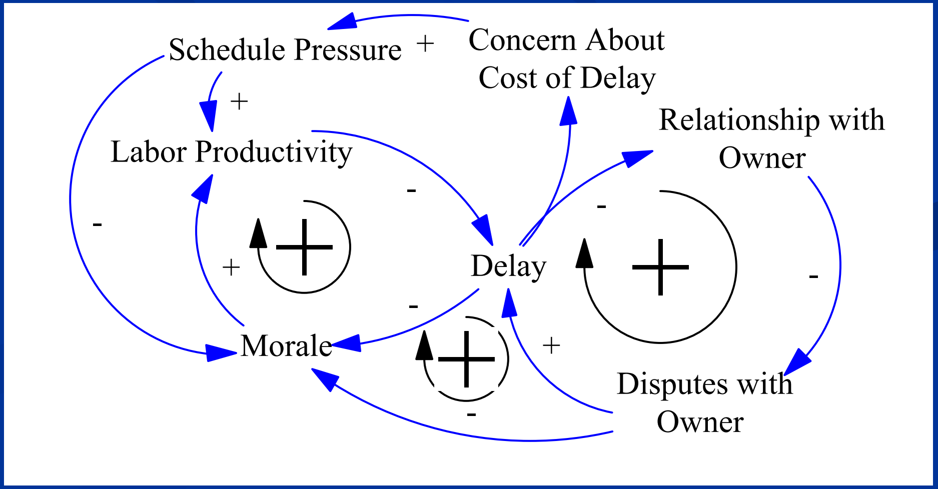


Evolving More Complex Diagrams

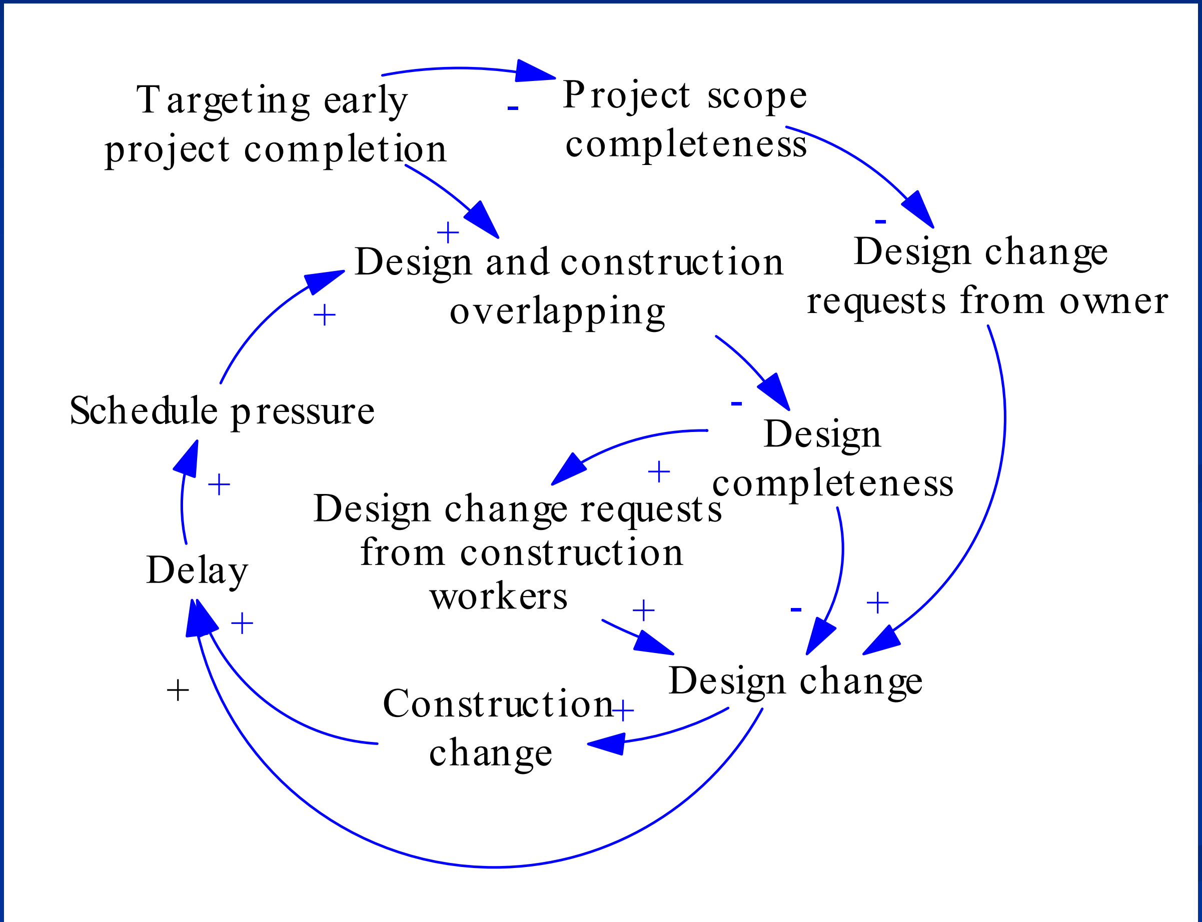




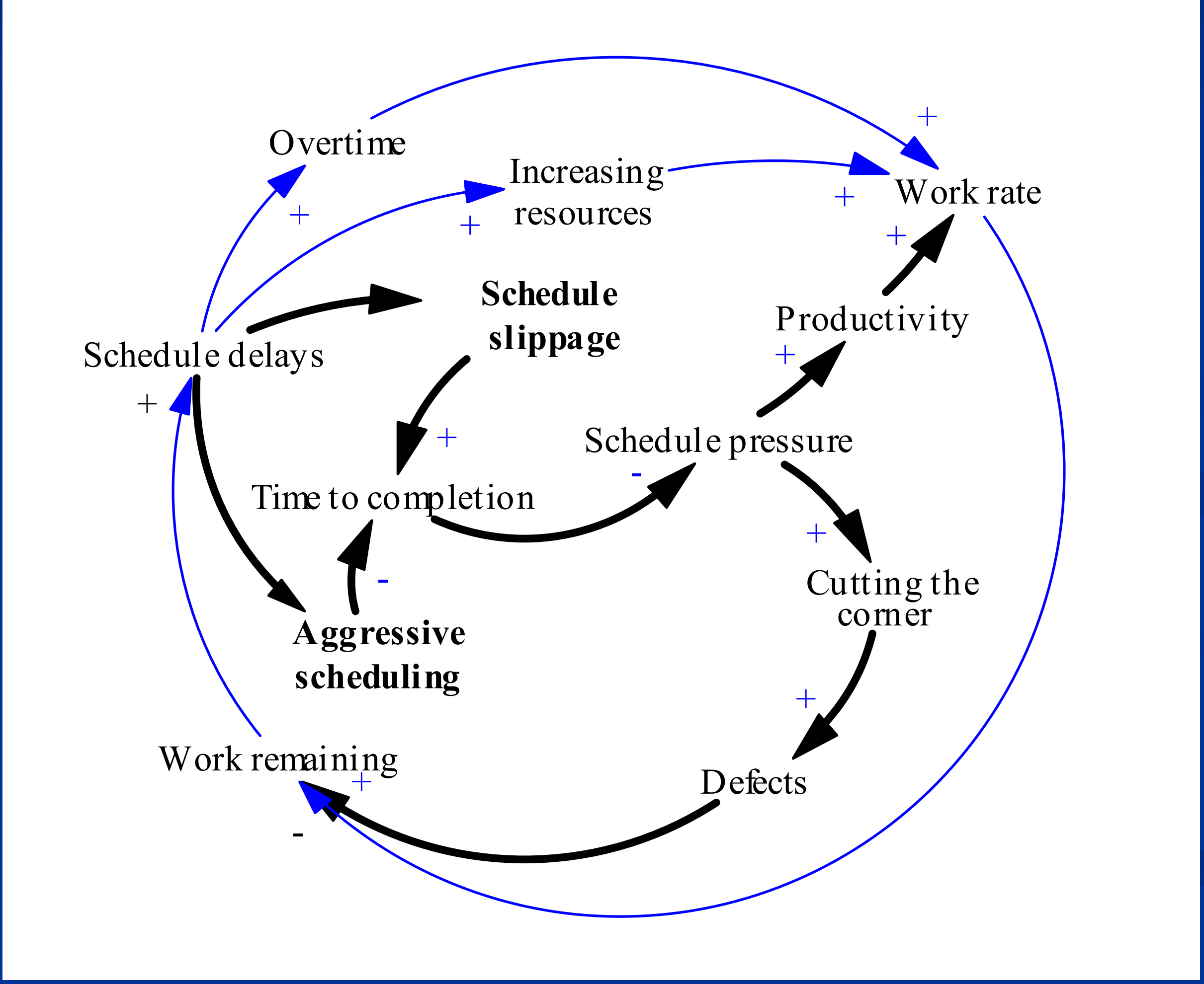




Causal loop example



Deadline and Milestone Control

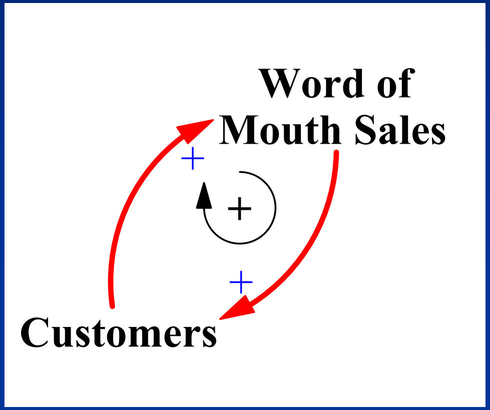


Causal Loop Structure : Dynamic Implications

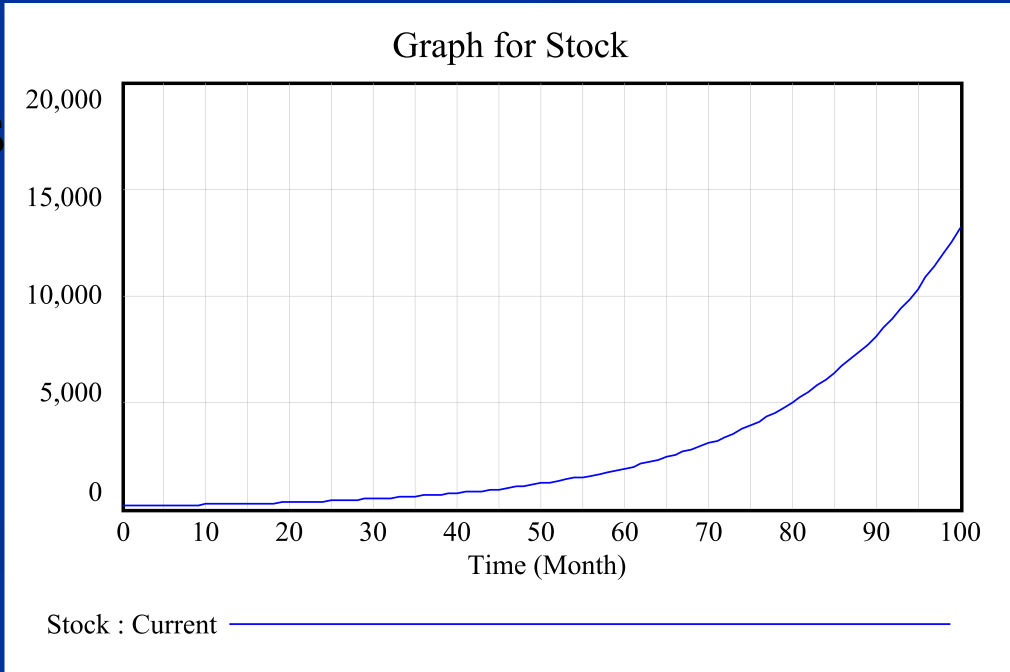
- **Each loop in a causal loop diagram is associated with qualitative dynamic behavior**
- **Most Common Single-Loop Modes of Dynamic Behavior**
  - Exponential growth
  - Goal Seeking Adjustment
  - Oscillation
- **When composed, get mixture of behaviors**
  - e.g. Growth and Plateau

CL Dynamics: Exponential Growth (First Order Reinforcing Loop)

- Example

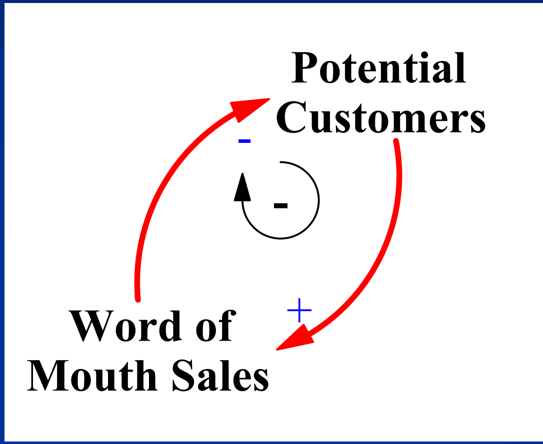


- Dynamic implications

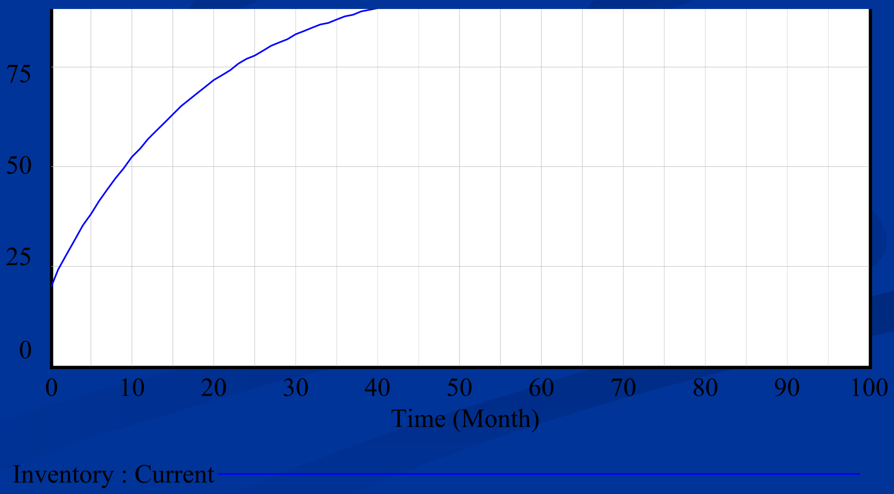


CL Dynamics: Goal Seeking (Balancing Loop)

- Example:

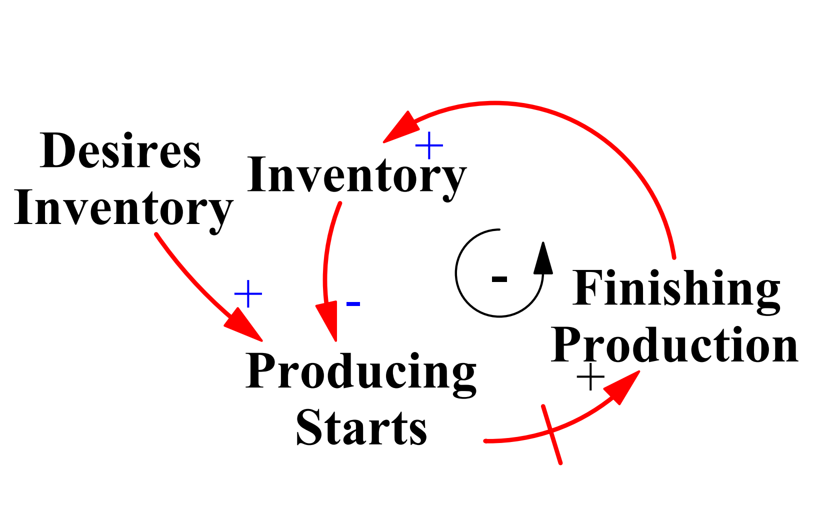


- Dynamic behavior

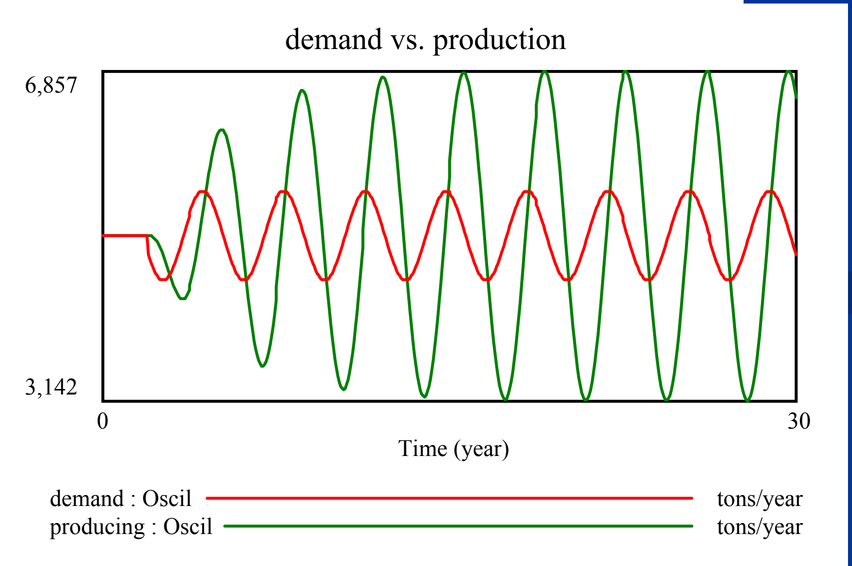


CL Dynamics: Oscillation (Balancing Loop with *Delay*)

- Causal Structure

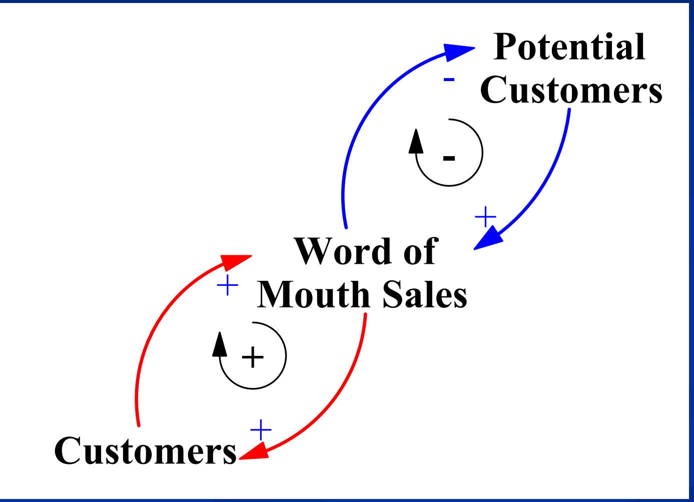


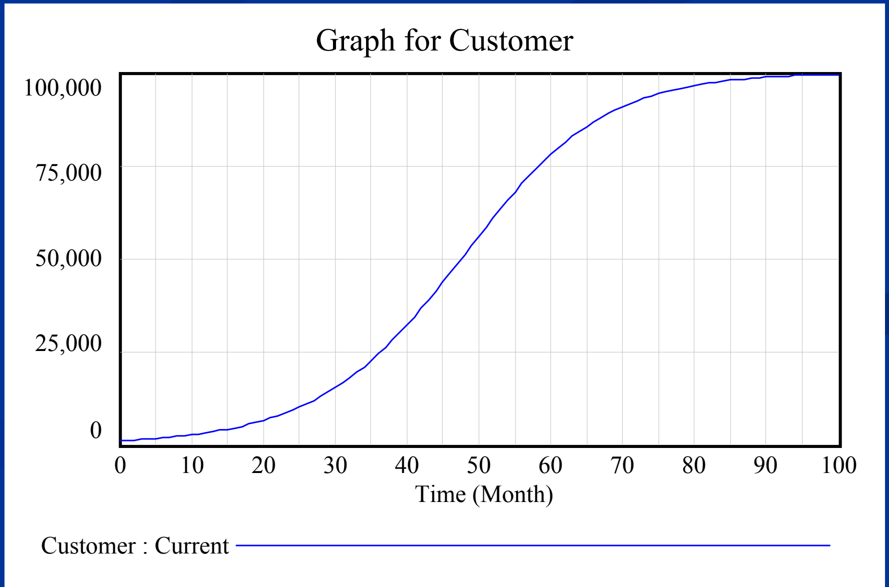
- Dynamic Behavior:



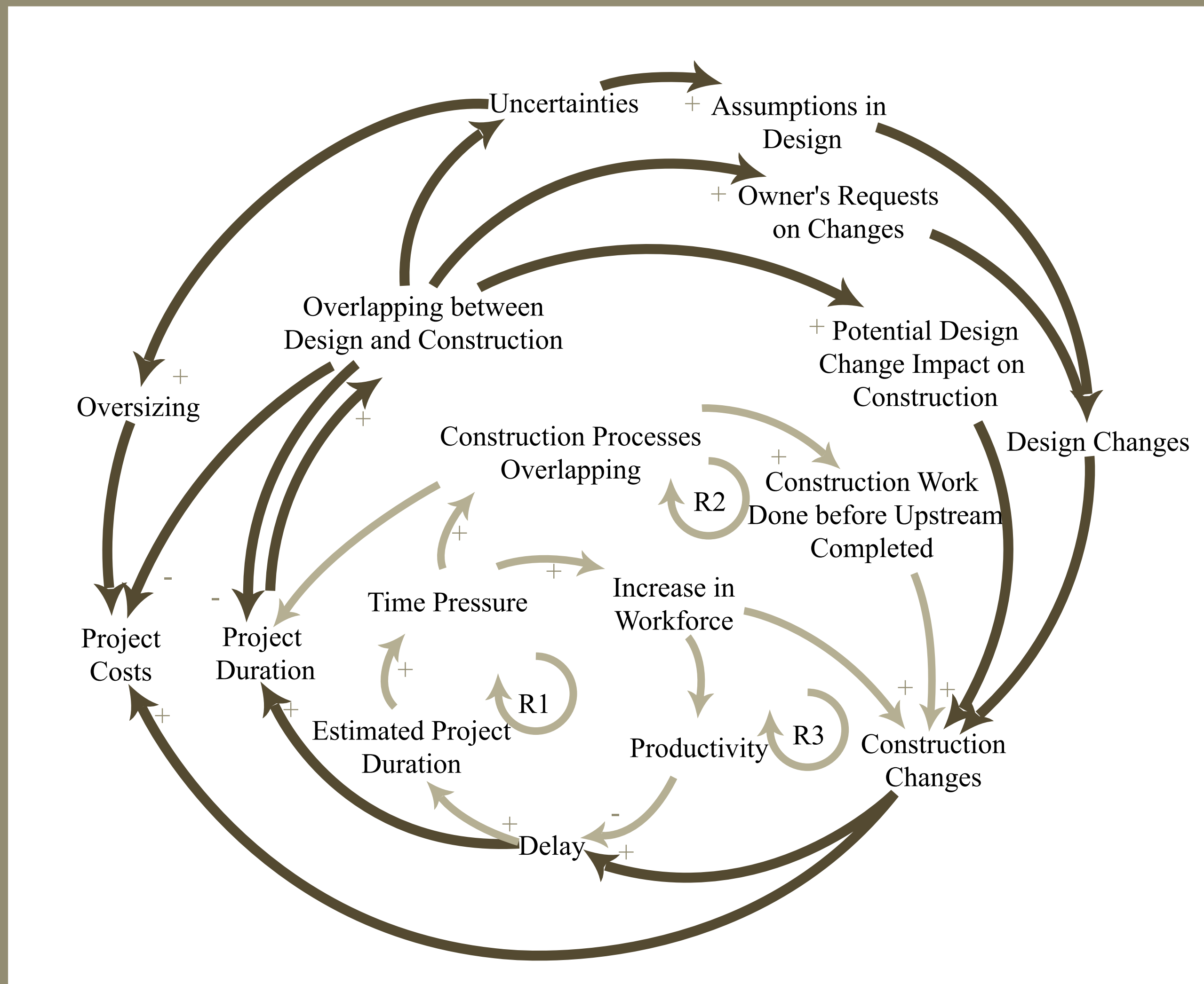
Growth and Plateau

- Loop structure:
  - Reinforcing Loop
  - Balancing Loop
- Dynamic Behavior:

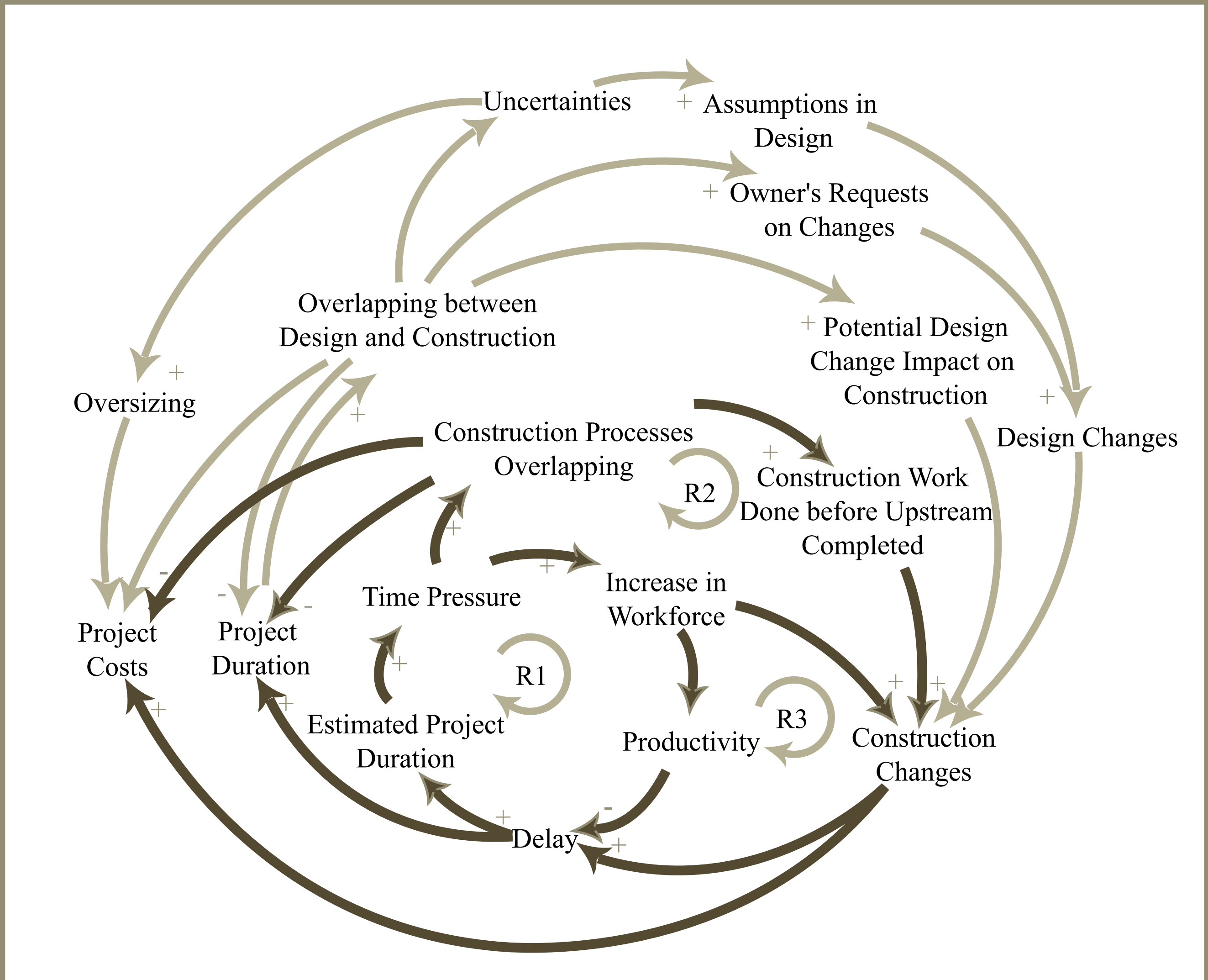




Design/Construction Overlap



Construction Phasing Overlap



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System Dynamics

- Many frameworks for project systems analysis
  - Discrete event sim., Agent-based sim.
  - System dynamics is most popular
- Greatest competitive advantage in systems that are
  - Nonlinear
  - Feedback rich
  - Exhibit delays
  - Less governed by low-level heterogeneity

System Dynamics Basics

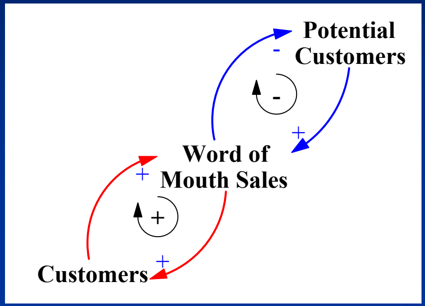
- Represents system as coupled series of ordinary differential equations (ODEs)
  - Standard state-equation formulation
  - Continuous time formulation
  - Stochastic components permissible (special handling)
  - Analytic solutions not possible: Numerically integrate
- Graphical representation for problem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

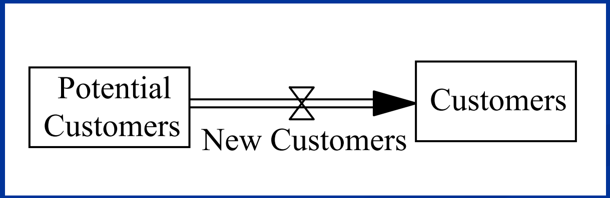
Example Creation of a System Dynamics Model

- Step 1: Map out Causal Loops



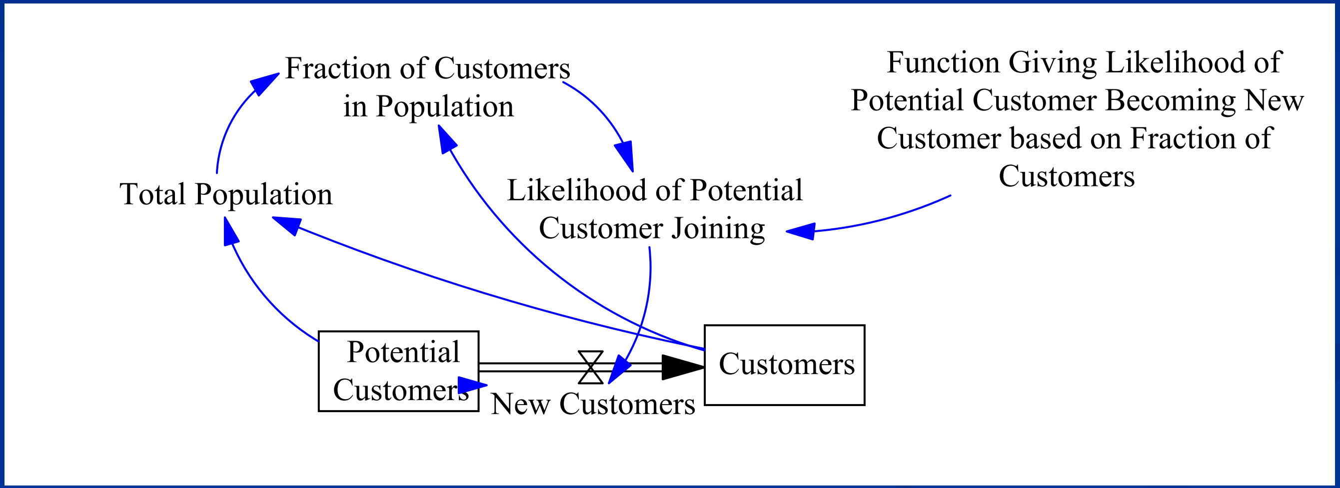
- Step 2: Identify state variables of interest

- Step 3: Identify flows of interest



Example Creation of a System Dynamics Model

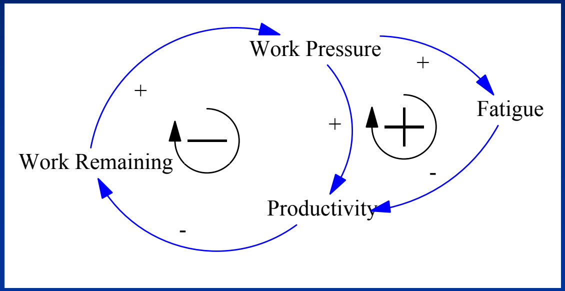
- Step 4: Define Supporting Variables



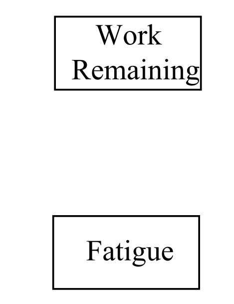
- Insert equations to describe linkages
  - E.g.
    - Total Population = Customers+Potential Customers
    - Fraction of Customers in Population= Customers/Total Population

Example Creation of a System Dynamics Model II

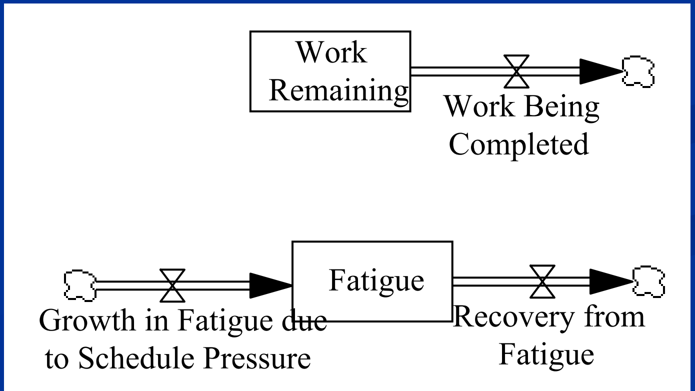
- Step 1: Map out Causal Loops



- Step 2: Identify state variables of interest



- Step 3: Identify flows of interest



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