To Main Proceedings Document

Evaluating the Time-to-Market and Quality Trade-off in Multi-Product Development Environments

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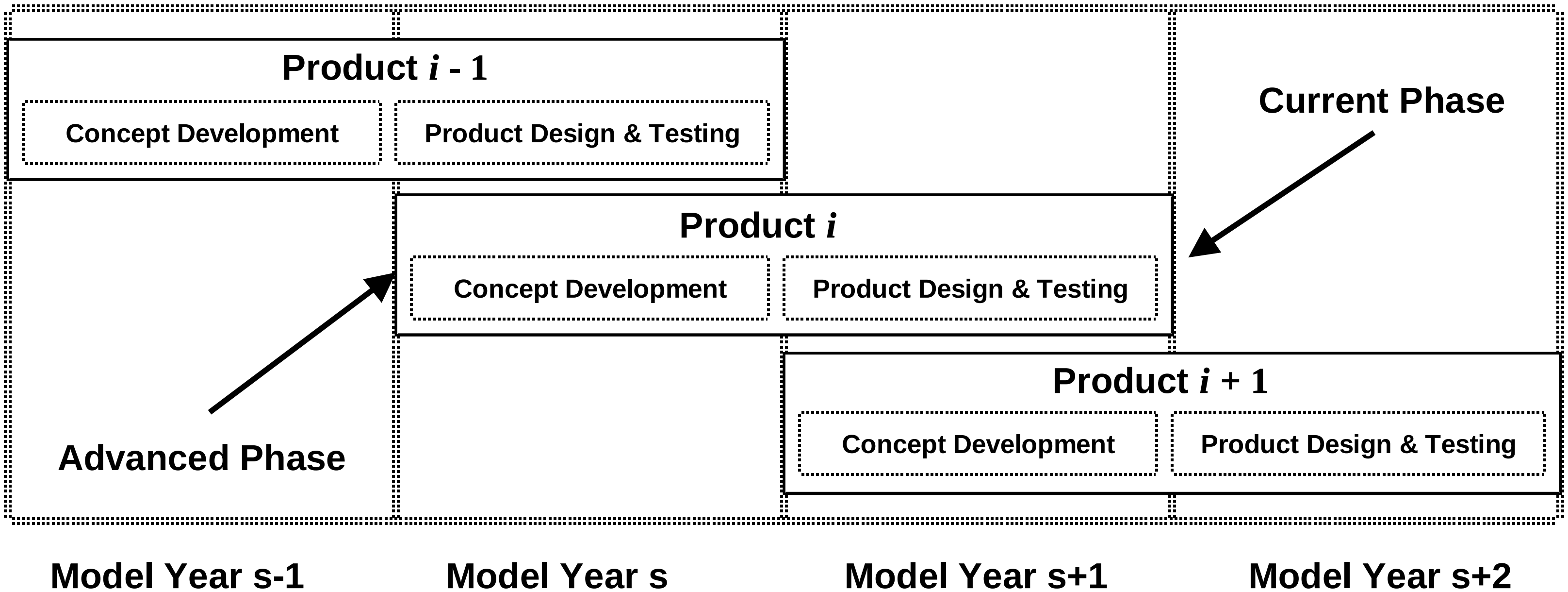
Motivating Issues

- Many organizations struggle to improve their product development processes.
- Performance does not always improve, despite substantial investment in the *design* of a new process.
- A better understanding of process *execution* is needed.

Approach One - Fixed Launch
Slip Quality to Meet Schedule

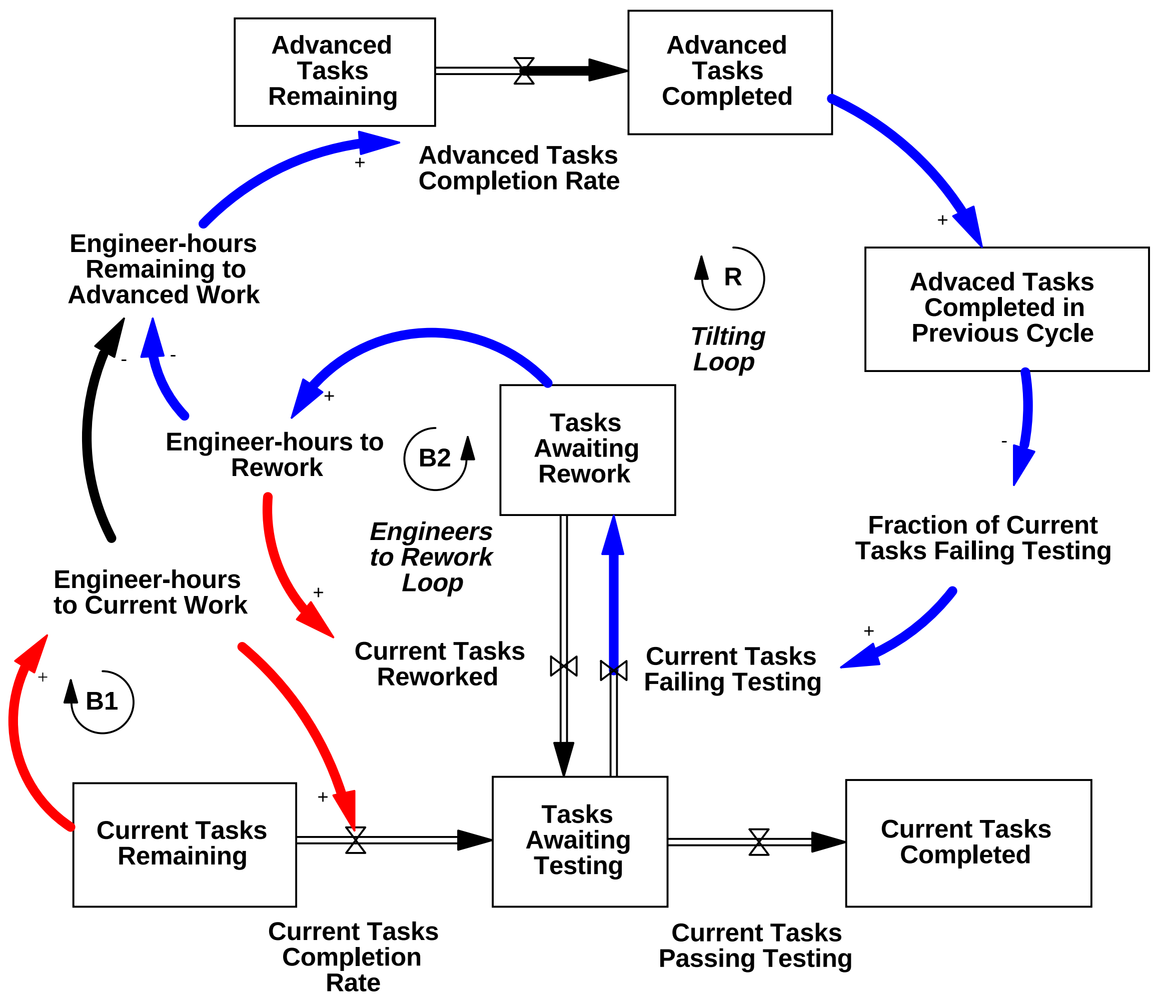
- *Allocation of scarce resources over two projects at different phases*
- *Assumption: Fixed launch date*



Model Assumptions

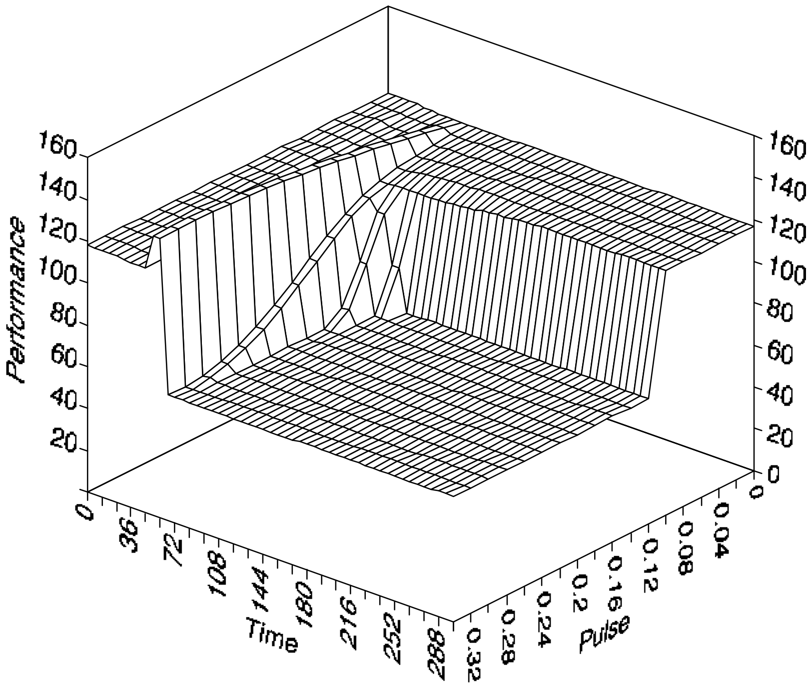
- Resources are scarce.
- Time-to-market is fixed.
- Projects are developed in two years and divided in two phases:
  - Concept development
  - Product design and testing
- Resources are transferable between projects and phases.
- Product design and testing takes priority over rework, which takes priority over concept development work.

Model Structure with Fixed Launch

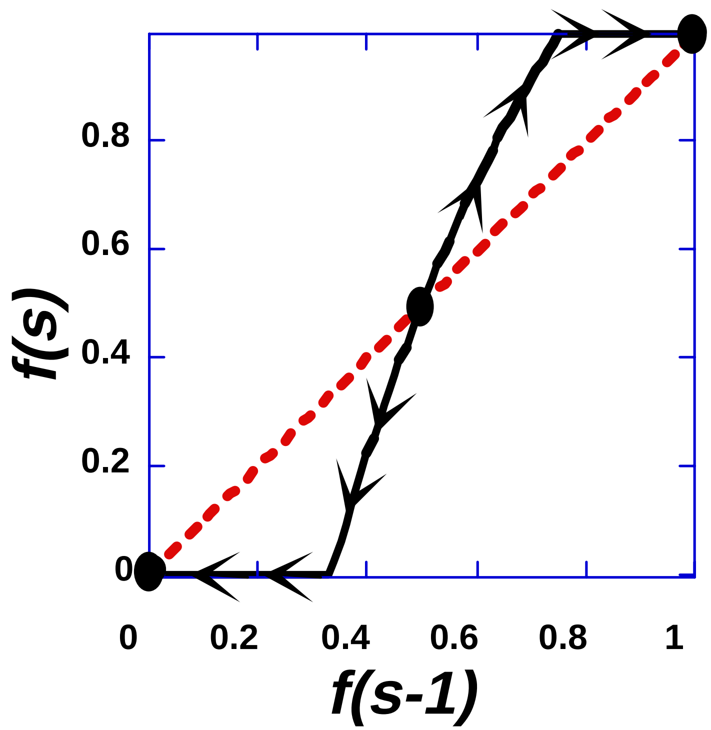


Gonçalves and Repenning, System Dynamics Group, MIT, 2000.

Results with Fixed Launch Date



Tilting from simulation



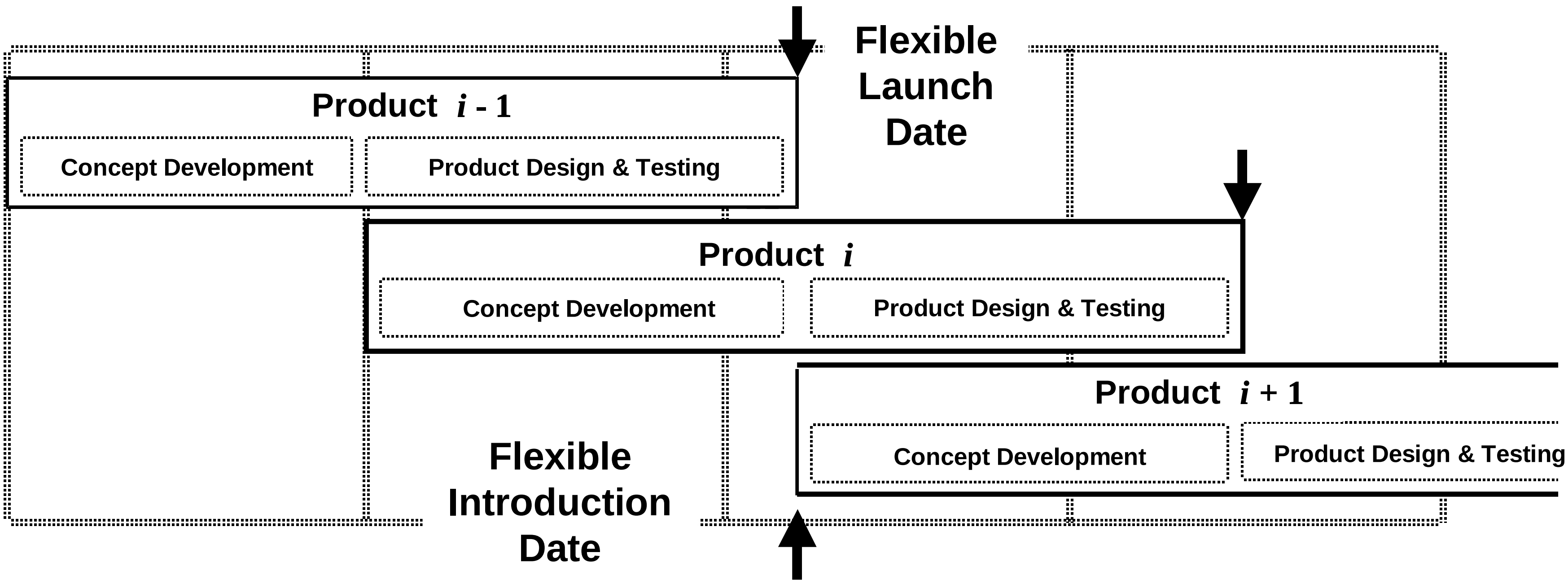
Multiple equilibria from analysis

Approach Two - Flexible Launch
Slip Schedule to Meet Quality

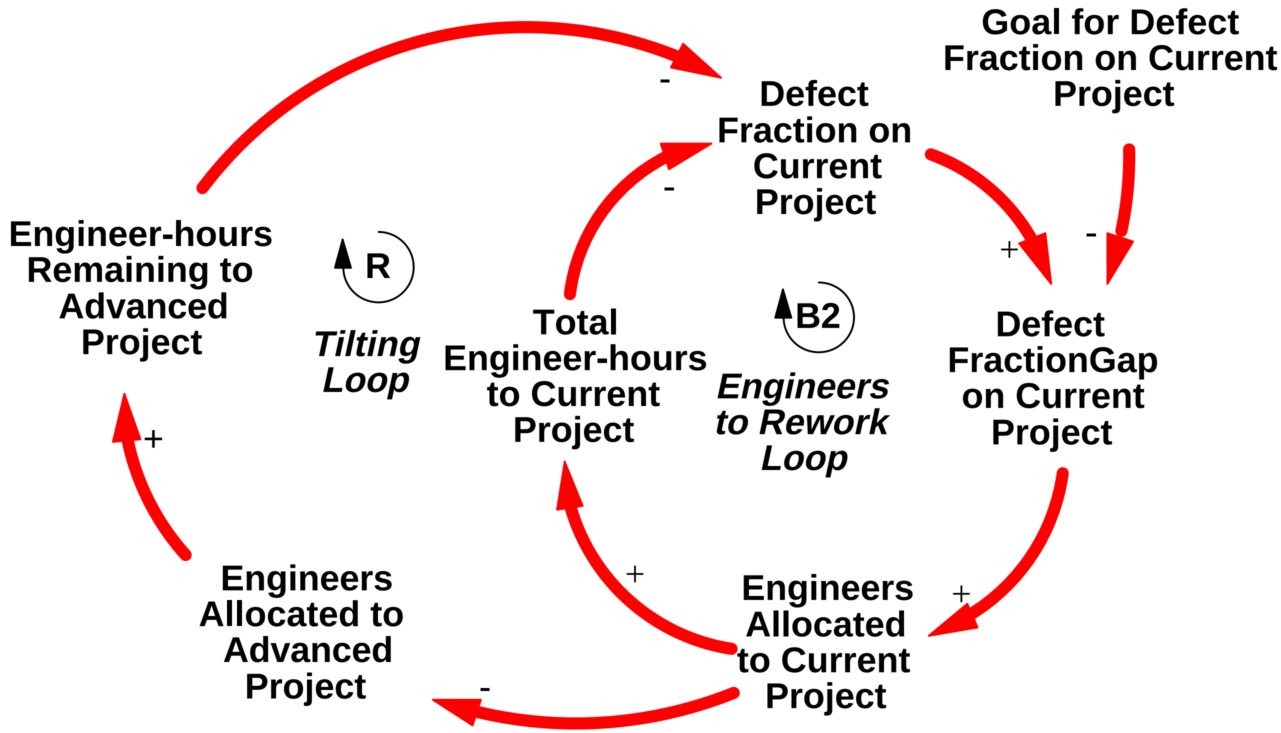
- Relax assumption of fixed launch date
  - Goal: Expand applicability of model
    - Fixed launch date appropriate only in limited contexts (automobiles, for example)
  - Means: Make launch contingent on a target quality
- Research questions:
  - How are the previous results contingent on the fixed launch date assumption?
  - Does project interdependence matter when the launch date can vary?

Relaxed Problem

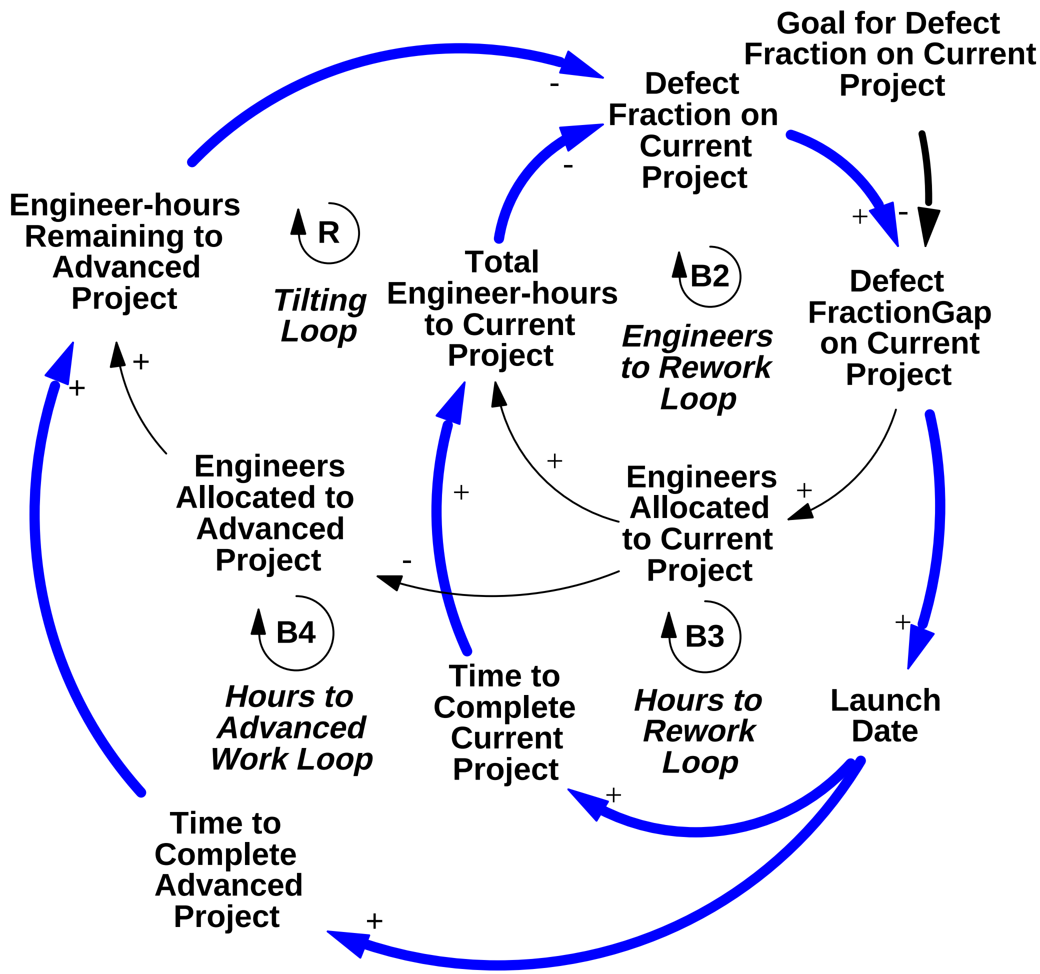
- *Allocation of scarce resources over two projects at different phases*
- *Assumption: Flexible launch date*



Causal Loops with Fixed Launch



Causal Loops with Flexible Launch



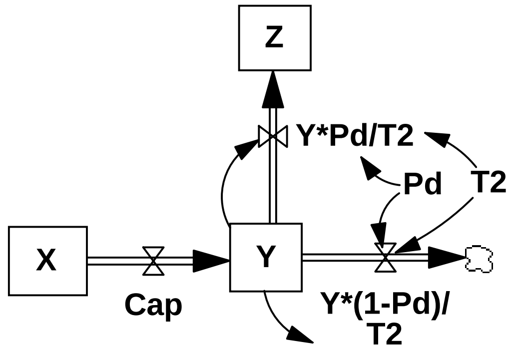
Analysis of the Relaxed Problem

- Sources of non-linearity
  - Product of states
    - *Testing outflow =* $(V(t)/\tau)*P_D$ *where:* $P_D(s)=P_a+P_b(1-f(s-1))$
  - Constraints on task completion rates
    - Limited by resources or maximum completion rate
- Phase plot analysis (*f(s)* vs. *f(s-1)*)
  - Avoid non-linearity from recursion: *between* projects analysis
  - Subsystems are piecewise linear: individual analysis of reduced problems

Reduced Systems

Nonlinear flow: dX/dt = Min(Cap, X/ τ_1 *)*

1



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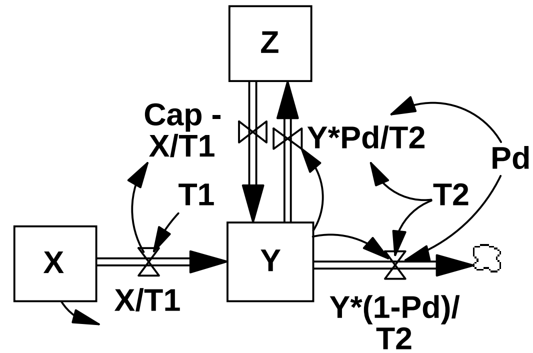
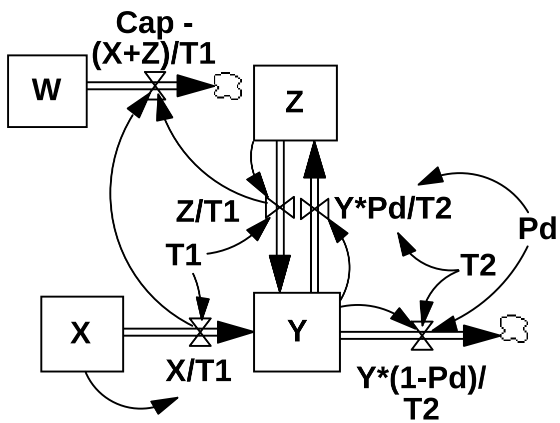


Nonlinear flow: dZ/dt = Min(Cap-X/ τ_1 *,Z/* τ_1 *)*

3



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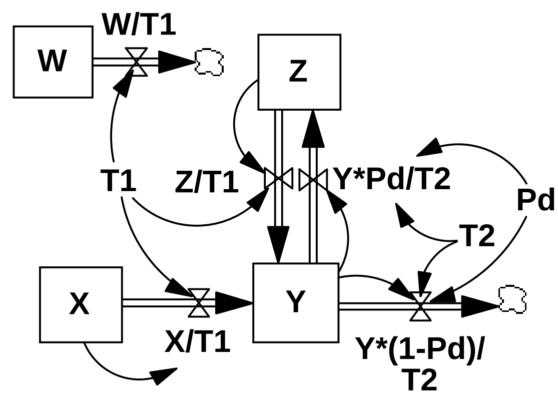


ODE's for Reduced Systems

1

$$\begin{cases} \dot{X} = -Cap \\ \dot{Y} = -Y/\tau_2 \\ \dot{Z} = Y \cdot P_D/\tau_2 \end{cases}$$

$$IC_1 = \{X_0 = x_0, Y_0 = 0, Z_0 = 0\}$$

2

$$\begin{cases} \dot{X} = -X/\tau_1 \\ \dot{Y} = Cap - Y/\tau_2 \\ \dot{Z} = Y \cdot P_D/\tau_2 - Cap + X/\tau_1 \end{cases}$$

$$IC_2 = \{X_0 = X_{f1}, Y_0 = Y_{f1}, Z_0 = Z_{f1}\}$$

3

$$\begin{cases} \dot{X} = -X/\tau_1 \\ \dot{Y} = X/\tau_1 + Z/\tau_1 - Y/\tau_2 \\ \dot{Z} = Y \cdot P_D/\tau_2 - Z/\tau_1 \\ \dot{W} = -Cap + X/\tau_1 + Z/\tau_1 \end{cases}$$

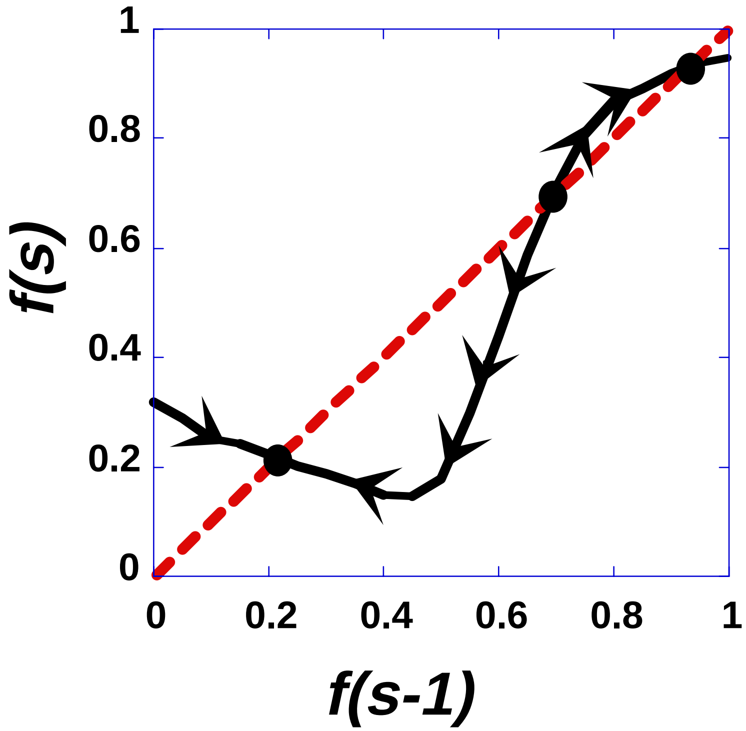
$$IC_3 = \{X_0 = X_{f2}, Y_0 = Y_{f2}, Z_0 = Z_{f2}, W_0 = w_0\}$$

4

$$\begin{cases} \dot{X} = -X/\tau_1 \\ \dot{Y} = X/\tau_1 + Z/\tau_1 - Y/\tau_2 \\ \dot{Z} = Y \cdot P_D/\tau_2 - Z/\tau_1 \\ \dot{W} = -W/\tau_1 \end{cases}$$

$$IC_4 = \{X_0 = X_{f3}, Y_0 = Y_{f3}, Z_0 = Z_{f3}, W_0 = W_{f3}\}$$

Multiple Equilibria from Analysis

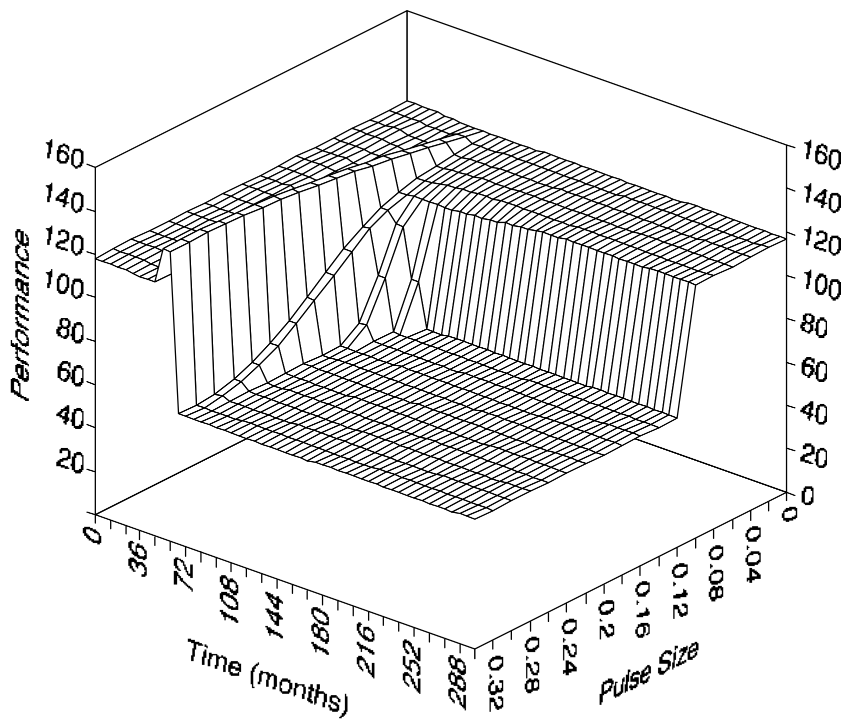


Analytical result with ***flexible*** *launch date*

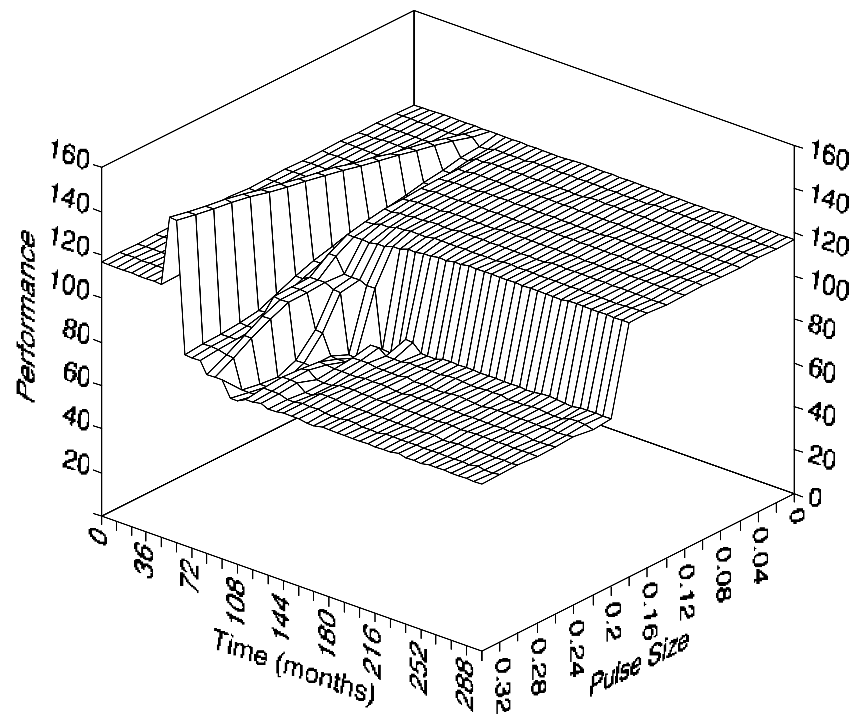
- The system has 3 equilibria.
- Two stable equilibria: *f*(s)* =.25, and *f*(s)* =.95
- The positive feedback loop dominates the behavior of the system and drives the system to one of the two stable equilibria.
- The unstable equilibrium determines the breaking point where the positive loop works as a vicious or virtuous cycle.

Performance

Pulse Size Sensitivity



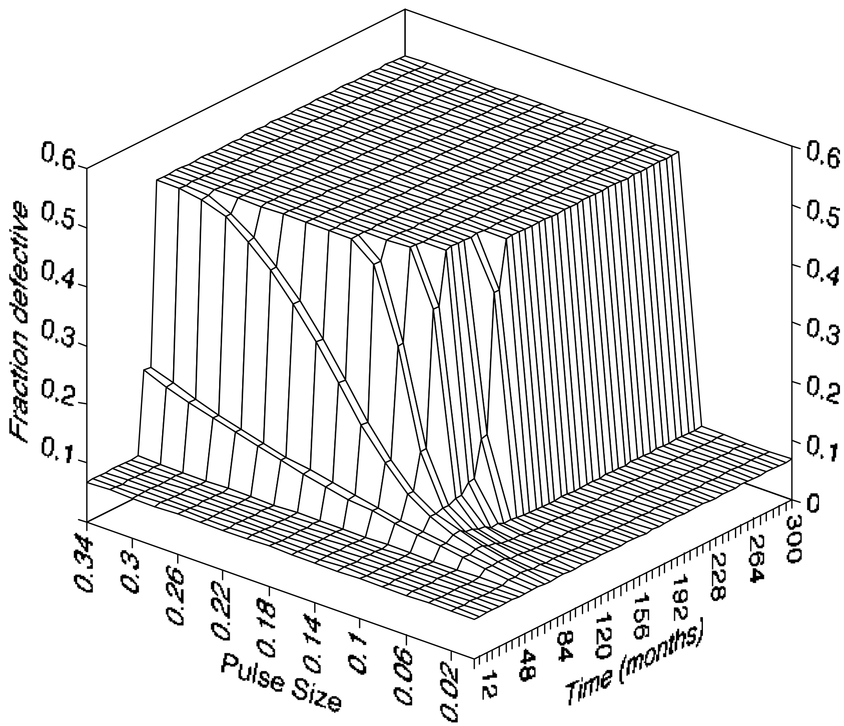
*with **fixed** launch date*



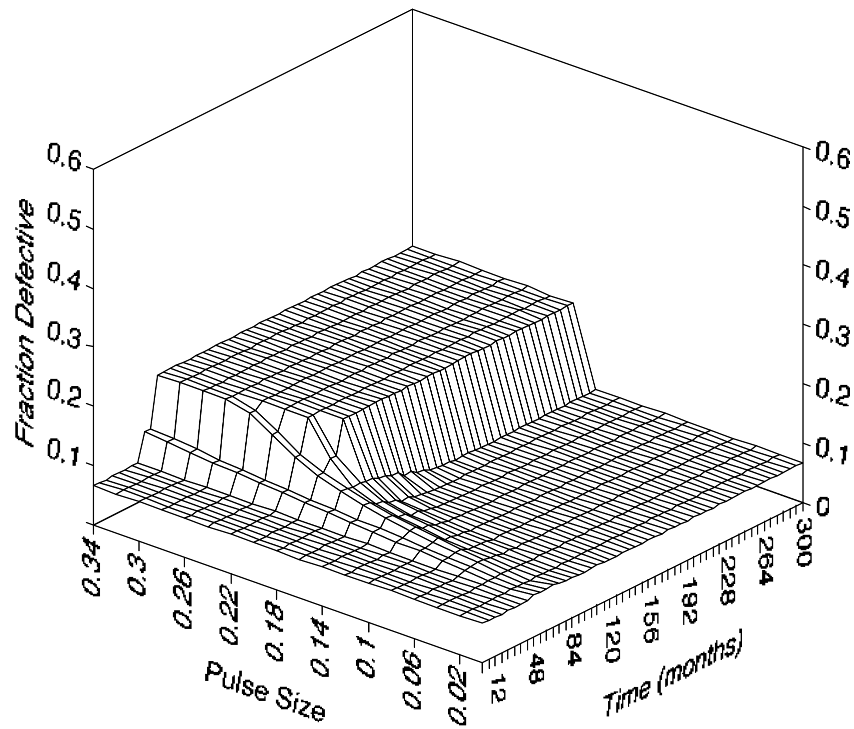
*with **flexible** launch date*

Gonçalves and Repenning, System Dynamics Group, MIT, 2000.

Defect Fraction
Pulse Size Sensitivity



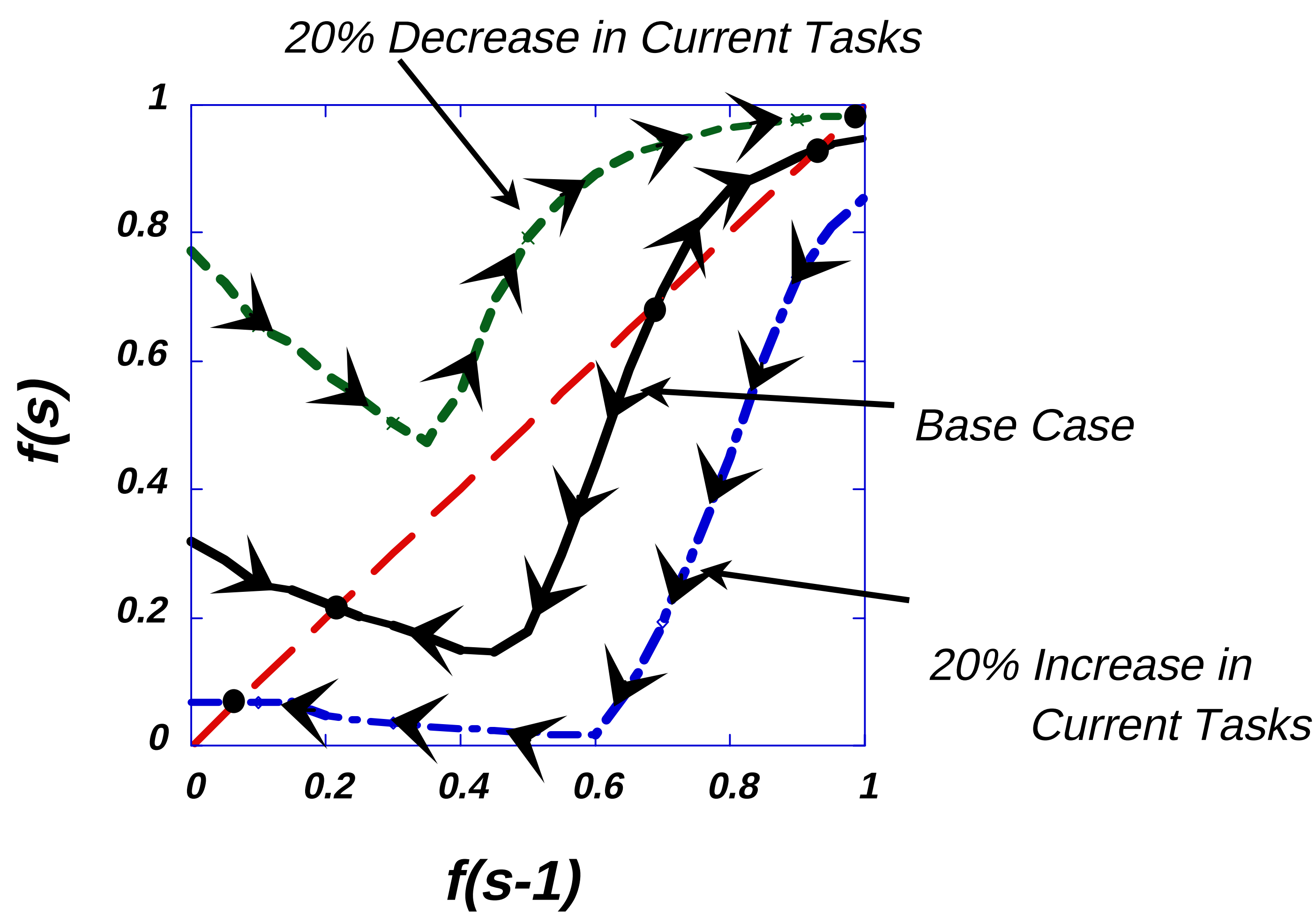
*with **fixed** launch date*



*with **flexible** launch date*

Sensitivity to Resource Utilization

Through Variation in Current Tasks



Gonçalves and Repenning, System Dynamics Group, MIT, 2000.

Loop Gain from Linearized State Transition Matrix

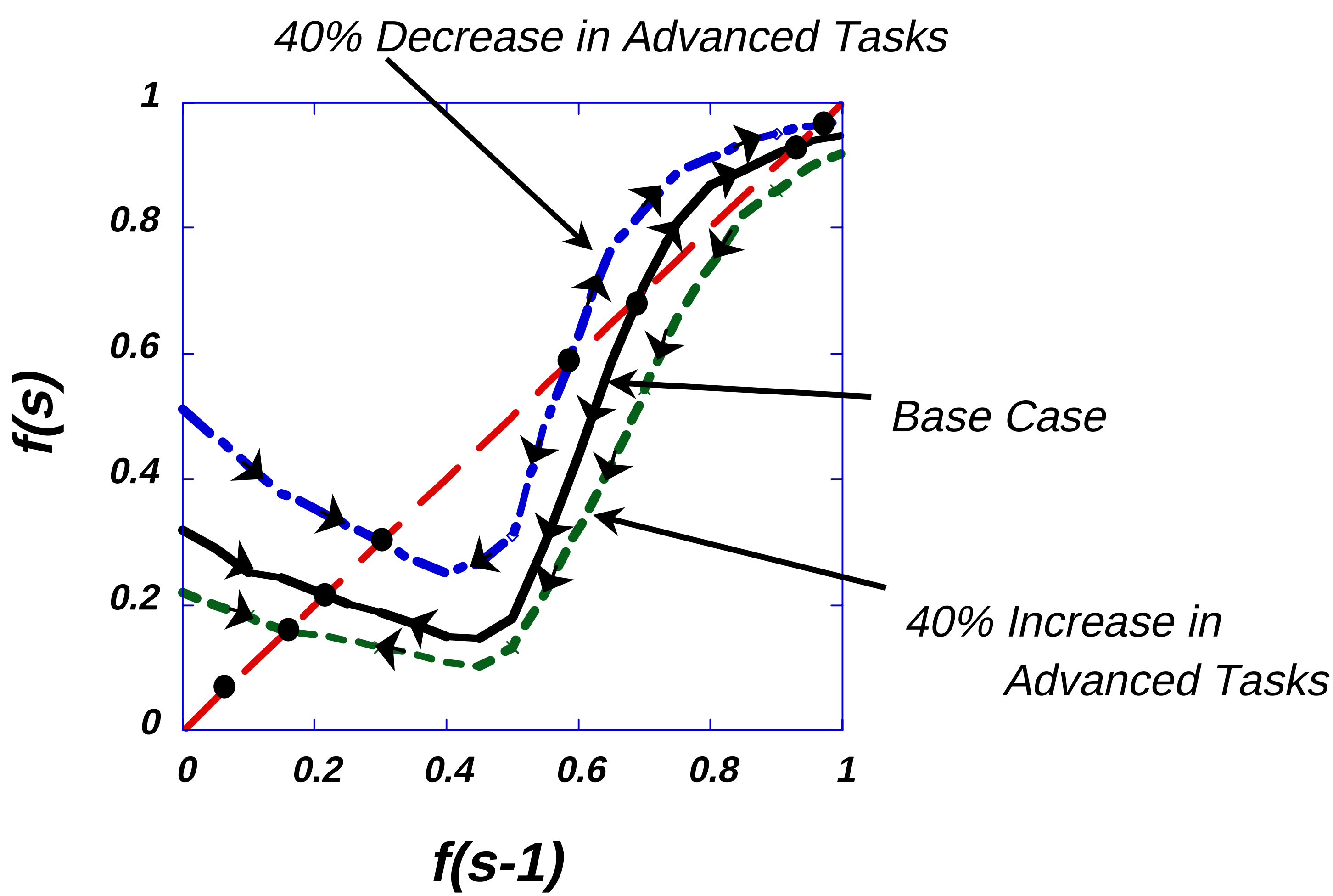
$$
\begin{bmatrix} \dot{X} \\ \dot{Y} \\ \dot{Z} \\ \dot{W} \\ \dot{W}_P \end{bmatrix} = \begin{bmatrix} -1/\tau_1 & 0 & 0 & 0 & 0 \\ 1/\tau_1 & -1/\tau_2 & 1/\tau_1 & 0 & 0 \\ 0 & (P_b W_{P0} + P_a W_T)/W_T\tau_2 & -1/\tau_1 & 0 & P_b Y_0 / W_T \tau_2 \\ 1/\tau_1 & 0 & 1/\tau_1 & 0 & 0 \\ 0 & 0 & 0 & 1/\tau_3 & -1/\tau_3 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ W \\ W_P \end{bmatrix} - \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \\ 0 \end{bmatrix} Cap
$$

$$
LoopGain = \frac{P_b}{\tau_1^2 \tau_2^2 \tau_3 W_T} Y_0
$$

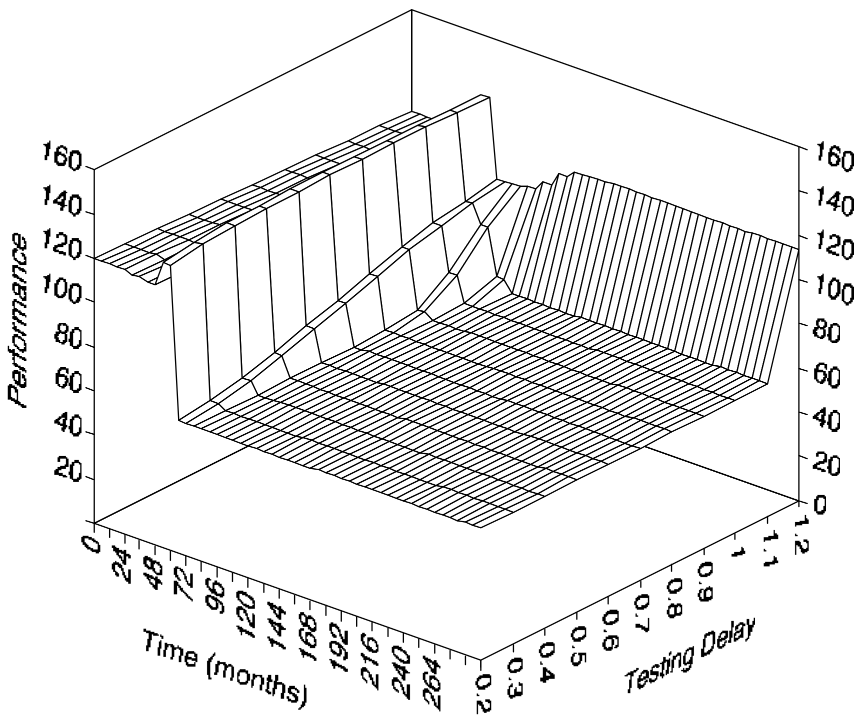
Y_0 = Value of Operating Point for Tasks in Testing;
P_b = Fraction of Avoidable Defects;
τ_1 = Minimum Time to Do Task;
τ_2 = Testing Delay;
τ_3 = Perception Delay;
W_T = Total Advanced Tasks; and
W_P = Fraction of Advanced Tasks Completed.

Sensitivity to Disequilibrium Dynamics

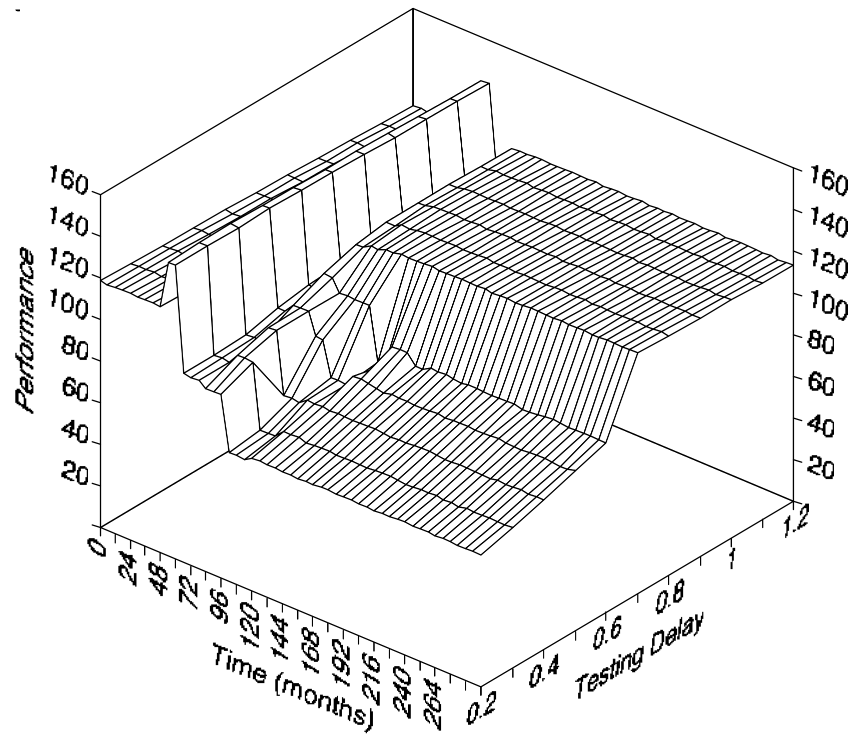
Through Variation in Advanced Tasks



Performance
Testing Delay Sensitivity



*with **fixed** launch date*



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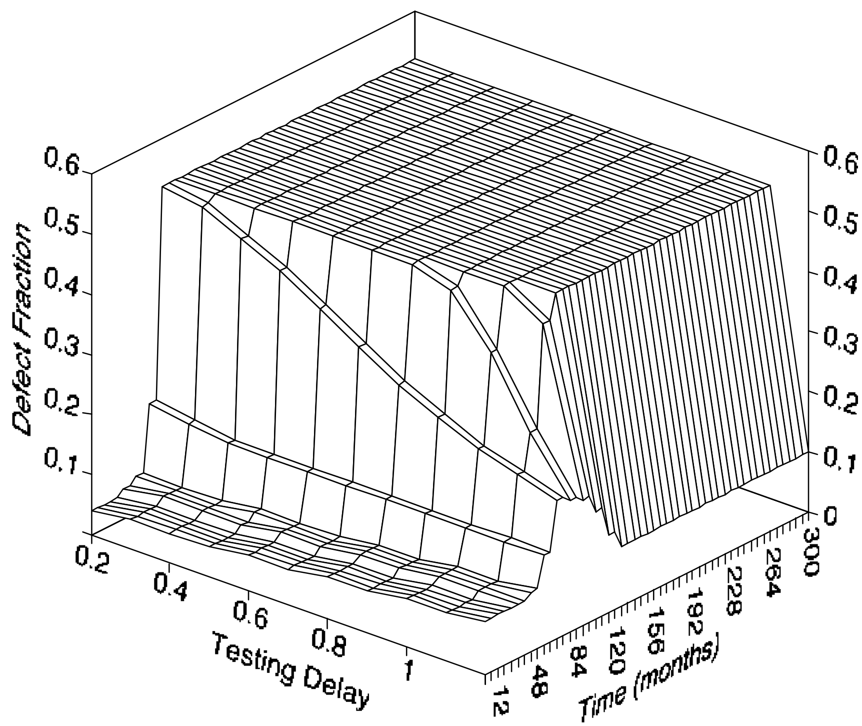
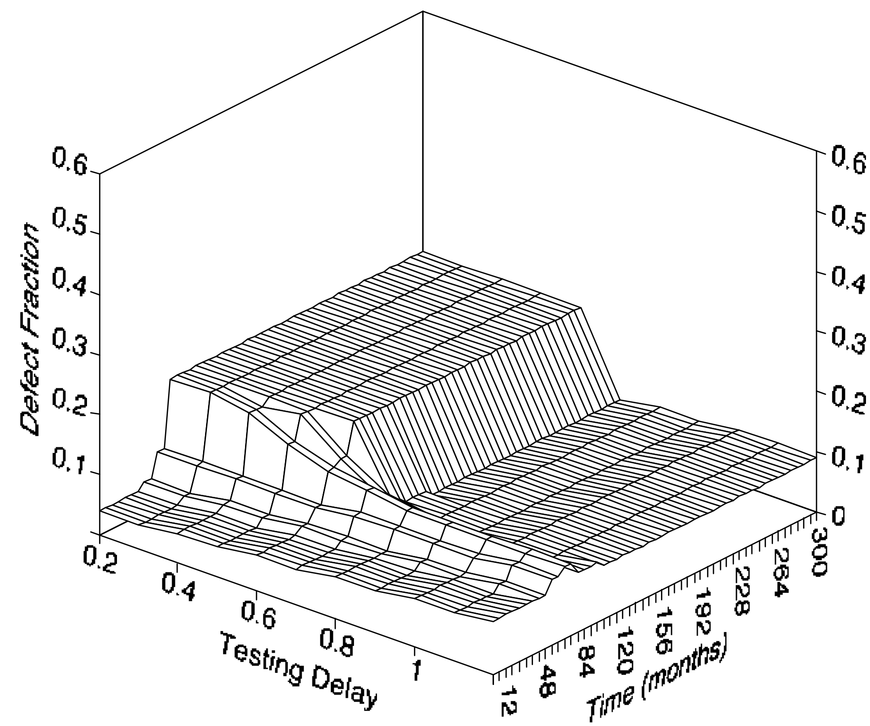
Defect Fraction
Testing Delay Sensitivity

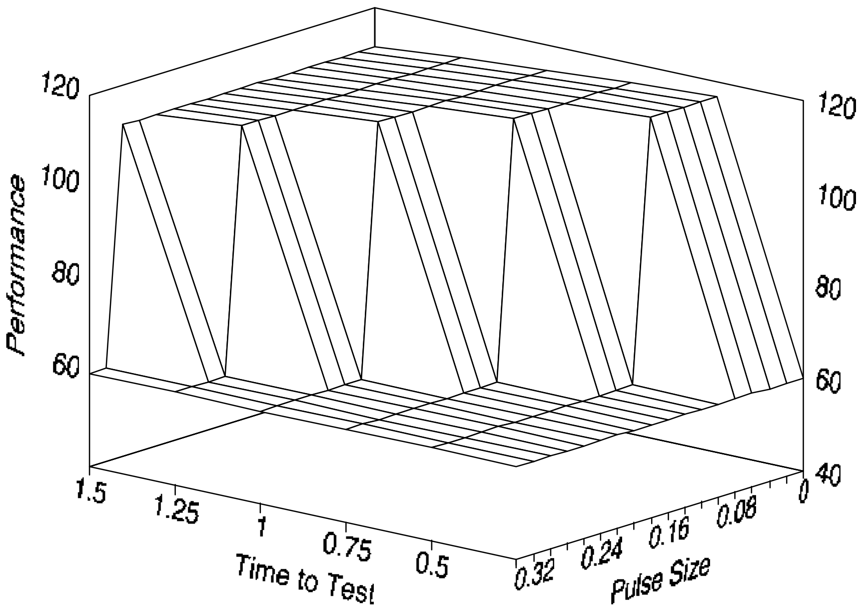


*with **fixed** launch date*

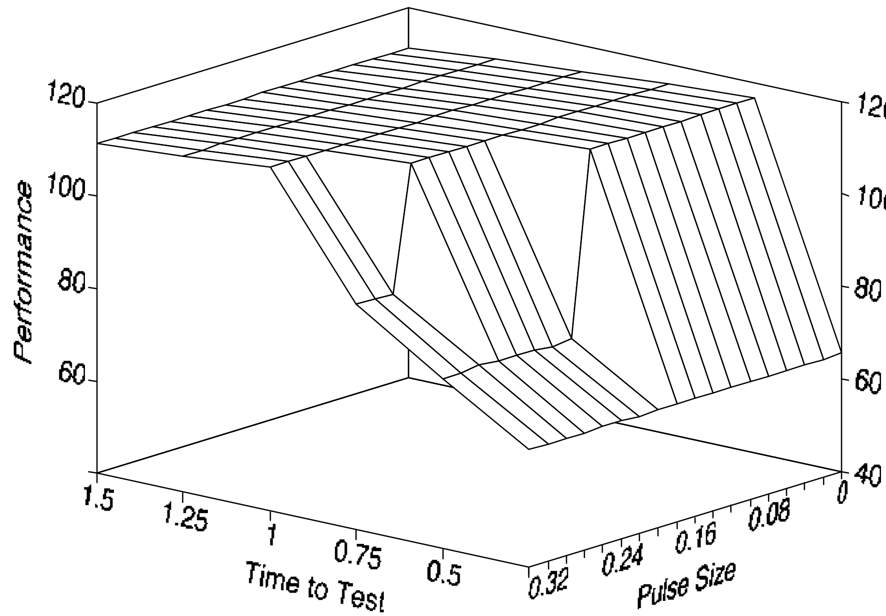


*with **flexible** launch date*

Steady State Performance

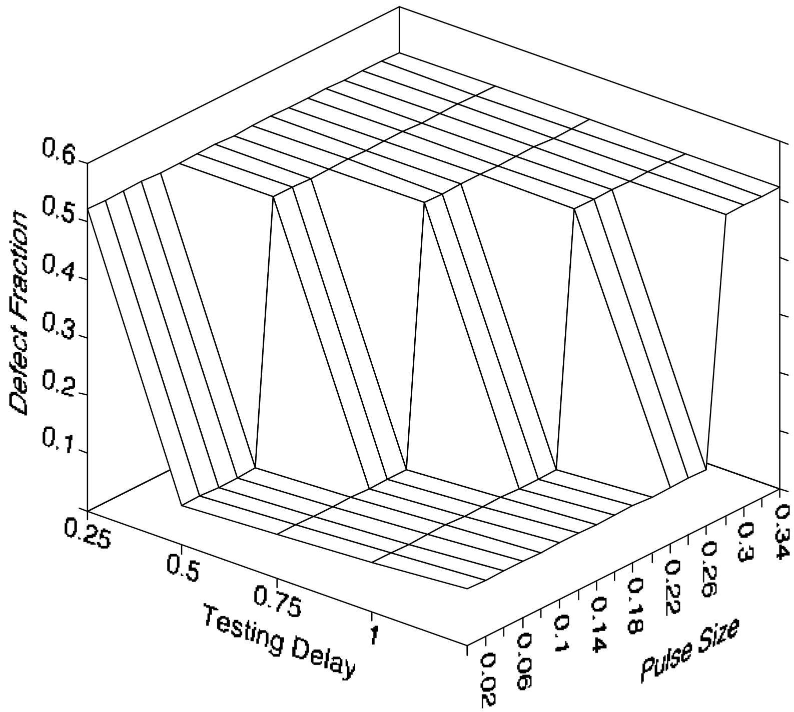


with **fixed** launch date

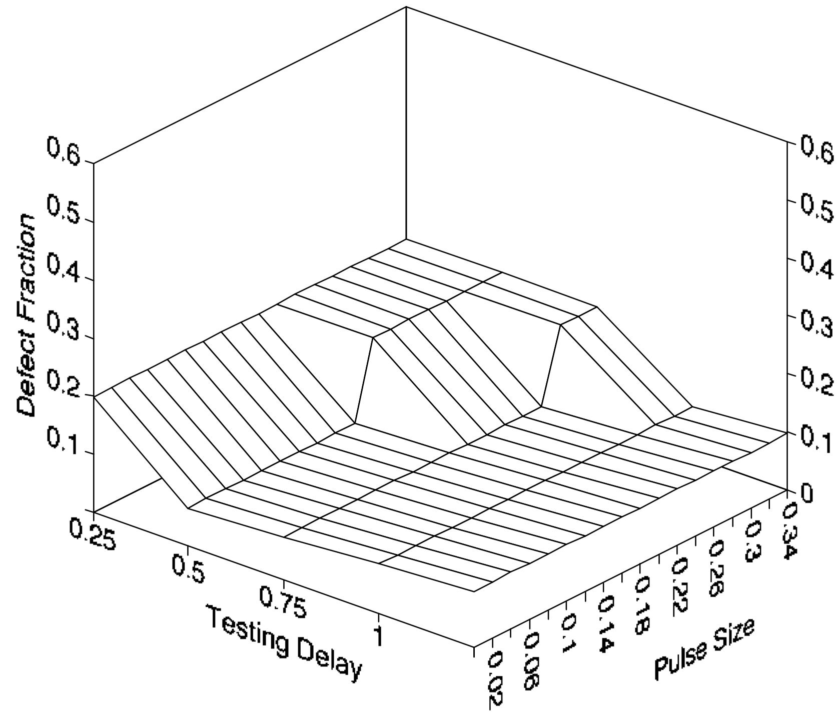


with **flexible** launch date

Steady State Defect Fraction



*with **fixed** launch date*

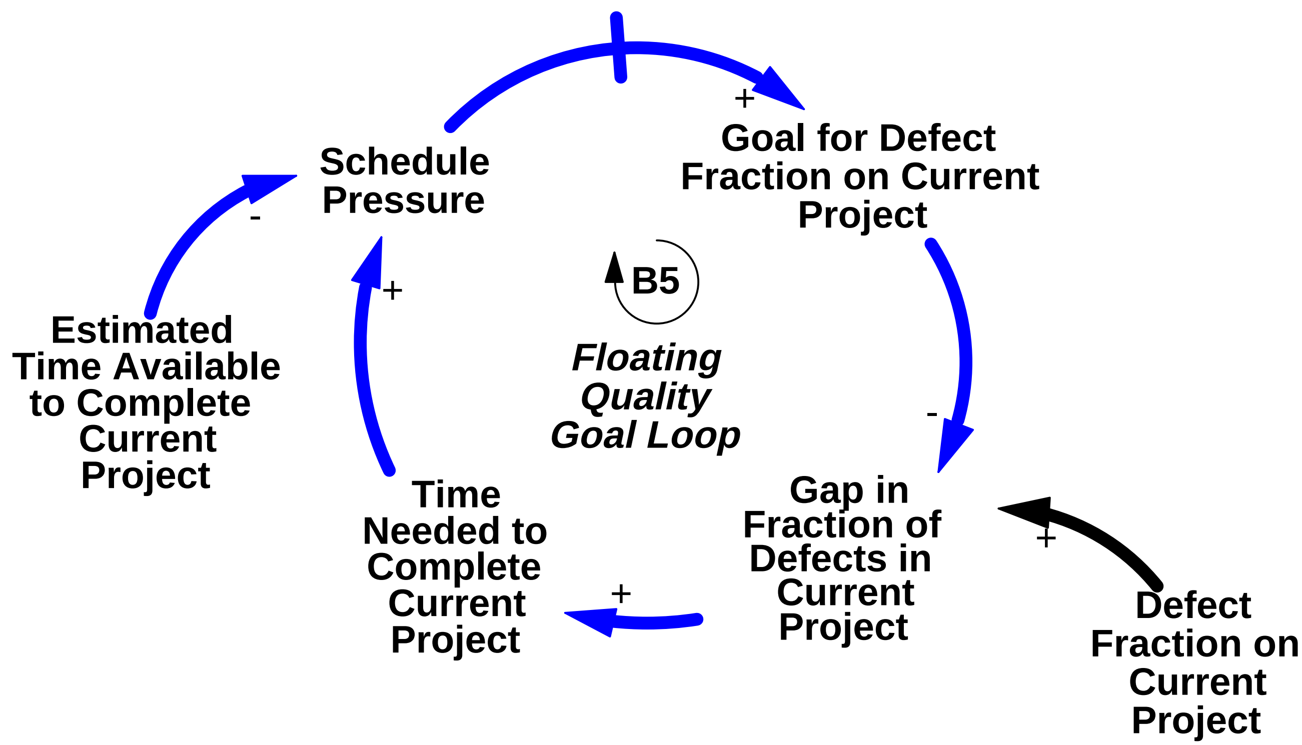


*with **flexible** launch date*

Introducing Floating Quality Goals

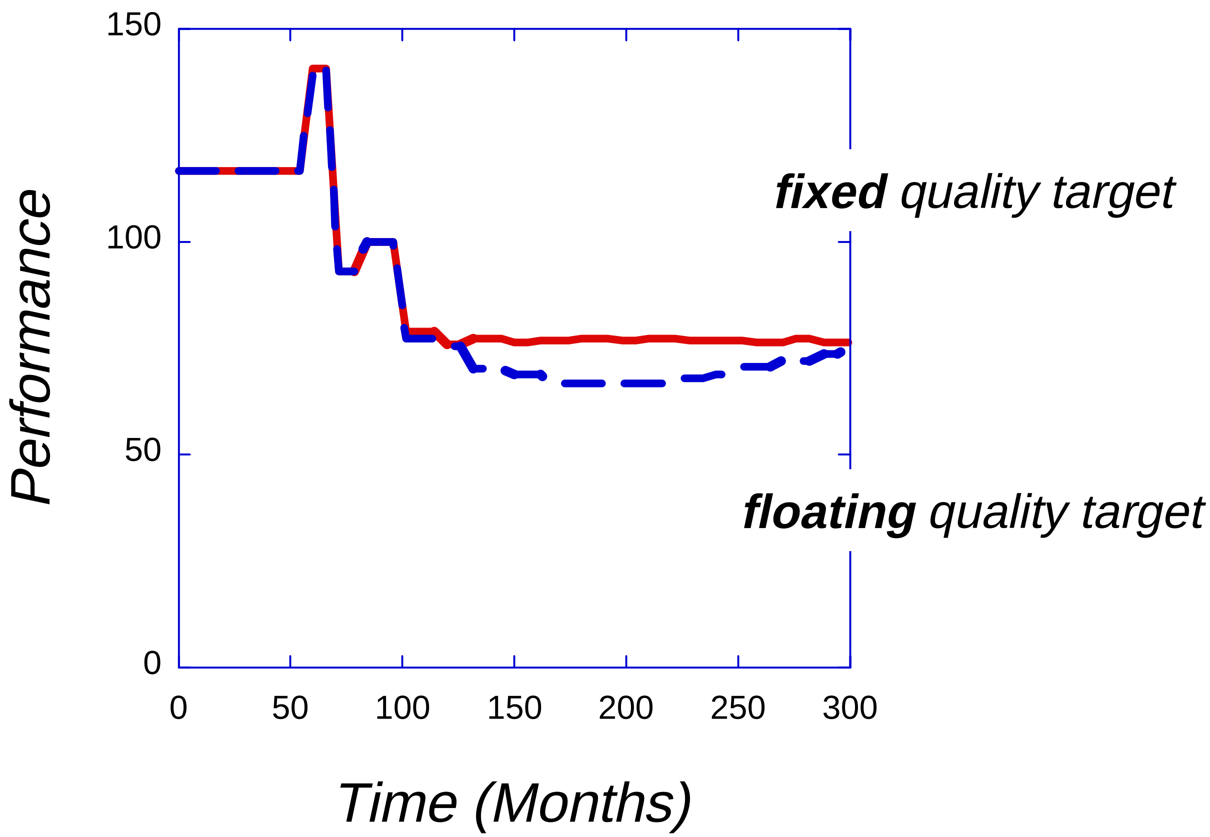
- Relax assumption of fixed quality target
  - Goal: Access trade-offs between time-to-market and quality
    A more realistic assumption under launch flexibility
  - Means: Make quality target contingent on schedule pressure
    - Schedule pressure = time required to finish a project / available time
- Research questions:
  - How are the previous results contingent on the fixed quality target assumption?

Model Structure with Flexible Quality



Performance with Flexible Quality

25% Pulse Size



Conclusions

Within the Scope of Our Model

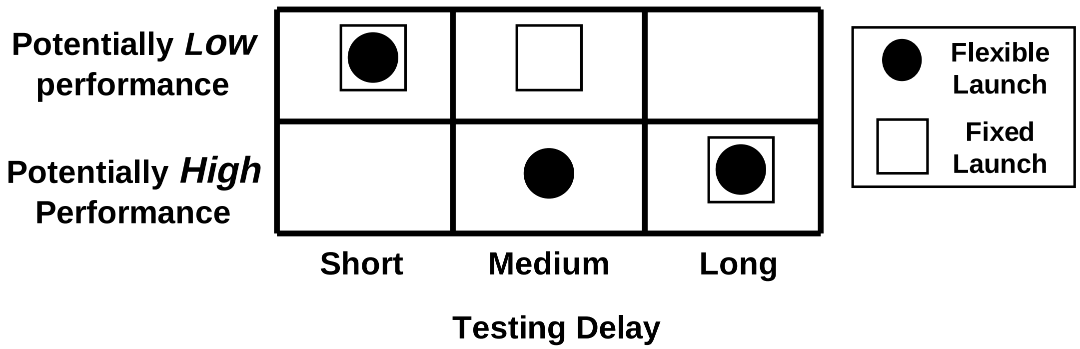
- Earlier results--project interdependence and possibility of *tilting*--still hold with a flexible launch.
- Launch flexibility increases system robustness --with a trade-off.
- We can characterize resource utilization and disequilibrium dynamics through loop gain.

Conclusions

Within the Scope of Our Model

- Compared to a fixed launch, we obtain more *limited* bounds for tilting phenomena.
- A *stronger* increase in transient workload is required to trap the system in a lower performance level.
- The trade-off for greater robustness is indeed a *permanently* longer development cycle time.

Toward Empirical Research



- In industries characterized by a fixed launch
  - We expect to find the tilting phenomenon more commonly.
  - These industries must have *LONG* testing delays to *AVOID* the tilting phenomenon.
- In industries characterized by a flexible launch
  - We do *NOT* expect to find the tilting phenomenon.
  - These industries must have a relatively *SHORT* testing delay to *PREVENT* the tilting phenomenon.