

# **A Model That Simulates A Significant Late Life Cycle Manpower Increase Phenomenon**

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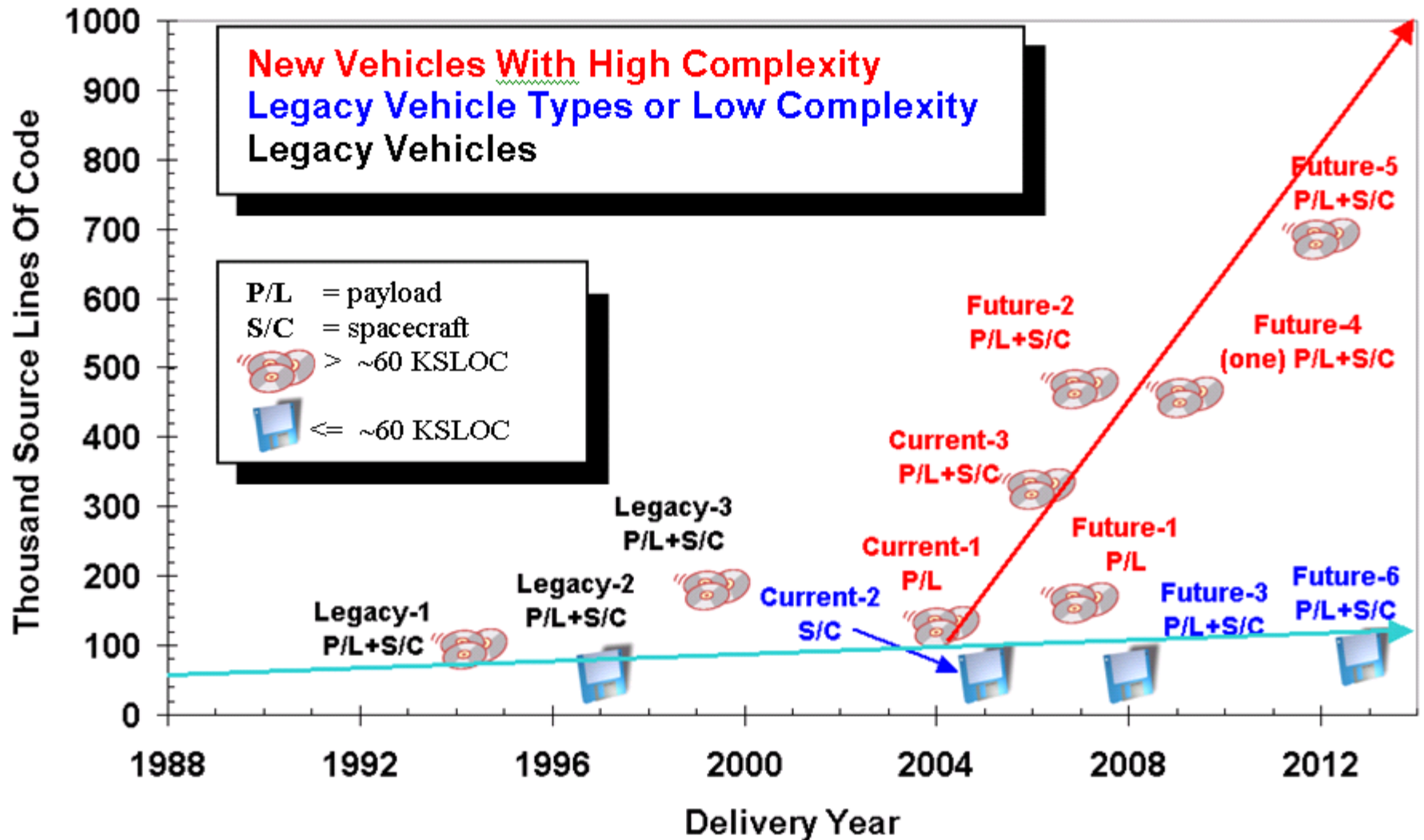
**The Aerospace Corporation**

# What I will discuss...

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- **Space and Missile Systems Center (SMC) flight software history**
- **The Aerospace Corporation's software reliability research database**
- **A project found in the database**
- **The System Dynamics model that simulates the phenomenon**

# SMC Flight SW History – Summer 2003



KSLOC is Thousand Source Lines Of Code

# Software Reliability Research Goals

- **In FY2004 The Aerospace Corporation began allocating Independent Research And Development (IRAD) funds to...**
  - ❖ **Begin archiving stove-piped software life cycle project data into a central repository to provide...**
    - Historical data to support our customer's dynamic project decisions
    - Quantitative analysis based on Software Reliability Engineering
    - A data supported method for Go/No Go launch decisions
  - ❖ **Support research to advance methods for software reliability prediction**
    - Increase the capability of early life cycle prediction methods
    - Allow external academic researchers access to 'cleansed' data

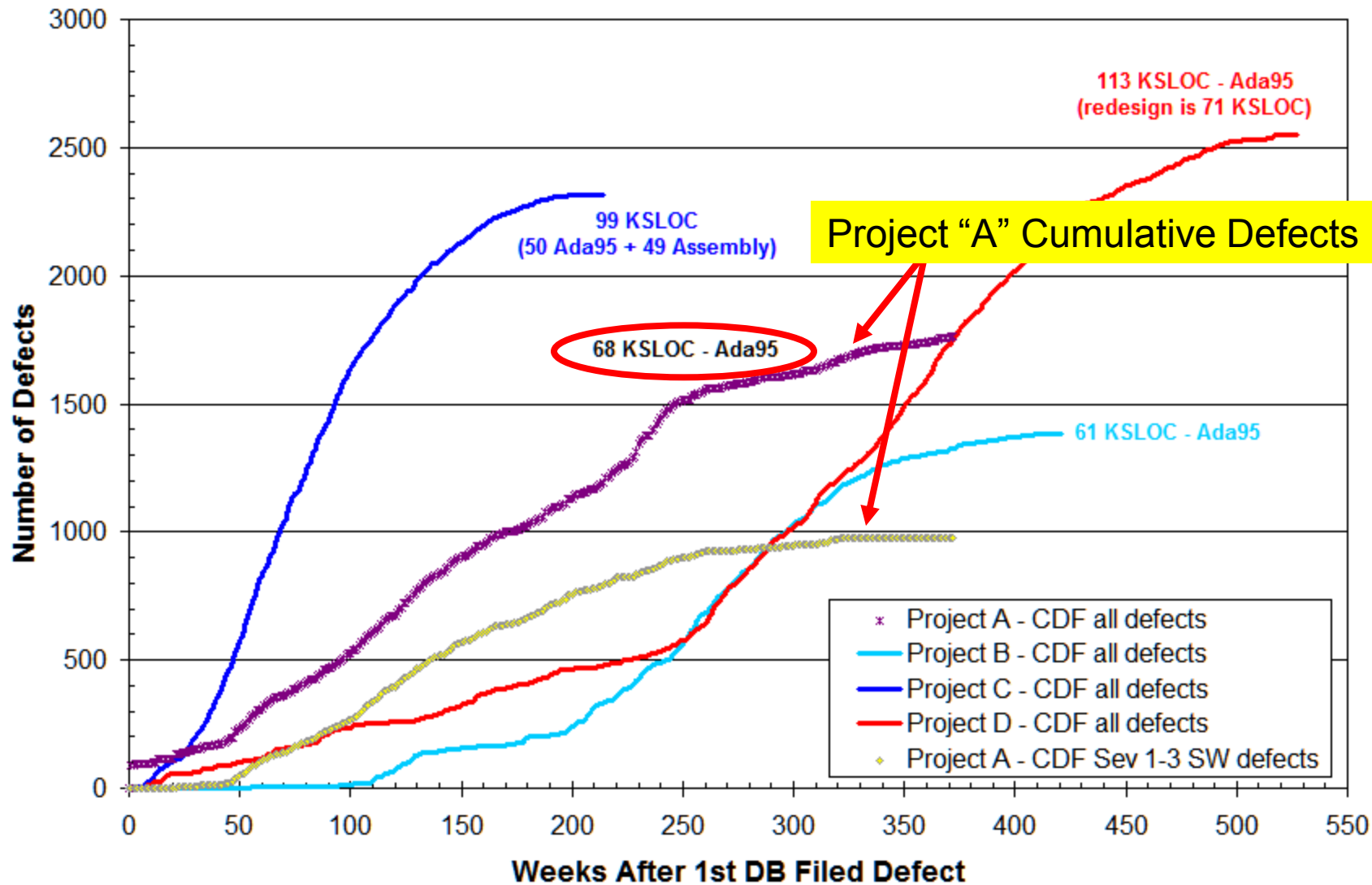
Hecht, M., and Buettner, D. J., "A Software Anomaly Repository To Support Software Reliability Prediction," *Proceedings of the Systems and Software Technology Conference*, (April 2005)

# 2008 Available Flight Software Project Data

	Project Labels						
	A	B	C	D	E	F	G
<b>Contractors Statement of Work or Objectives (CSOW or SOO)</b>	Y	Y	Y	Y	Y	Y	Y
<b>Software Development Plan (SDP)</b>	Y <sup>1</sup>	Y <sup>1</sup>	Y <sup>1</sup>	Y <sup>1</sup>	Y <sup>1</sup>	Y <sup>1</sup>	Y
<b>Preliminary Design Review (PDR)</b>	Y	Y	Y <sup>1</sup>	Y	Y	Y	N
<b>Critical Design Review (CDR)</b>	Y	Y	Y <sup>1</sup>	Y	Y	Y	Y
<b>Algorithm Design Document (ADD)</b>	Y <sup>1</sup>	Y <sup>1</sup>	Y <sup>1</sup>	Y <sup>1</sup>	N	N	N
<b>Software Design Description (SDD)</b>	Y <sup>1</sup>	Y <sup>1</sup>	Y <sup>1</sup>	Y <sup>1</sup>	N	N	Y
<b>Software source code</b>	Y <sup>1</sup>	Y <sup>1</sup>	Y <sup>1</sup>	Y <sup>1</sup>	Y	N	N
<b>Software Defect Repository (SDR)</b>	Y <sup>1</sup>	Y <sup>1</sup>	Y <sup>1</sup>	Y <sup>1</sup>	Y*	N	N
<b>Various project briefings, reports and metrics</b>	Y	Y	Y	Y	Y	Y	Y
<b>Researcher observations and interviews</b>	Y	Y	Y	Y	Y	N	Y
<b>N</b>	No data. (Data was not made available to the researcher.)						
<b>Y*</b>	Limited data available to the researcher.						
<b>Y<sup>1</sup></b>	Multiple versions available from numerous revisions.						
<b>Projects C and D</b>	Both went through a re-design after architectural design issues were found.						
<b>Bold Blue Text</b>	The focus of the quantitative data analysis was selected to support dynamic modeling.						

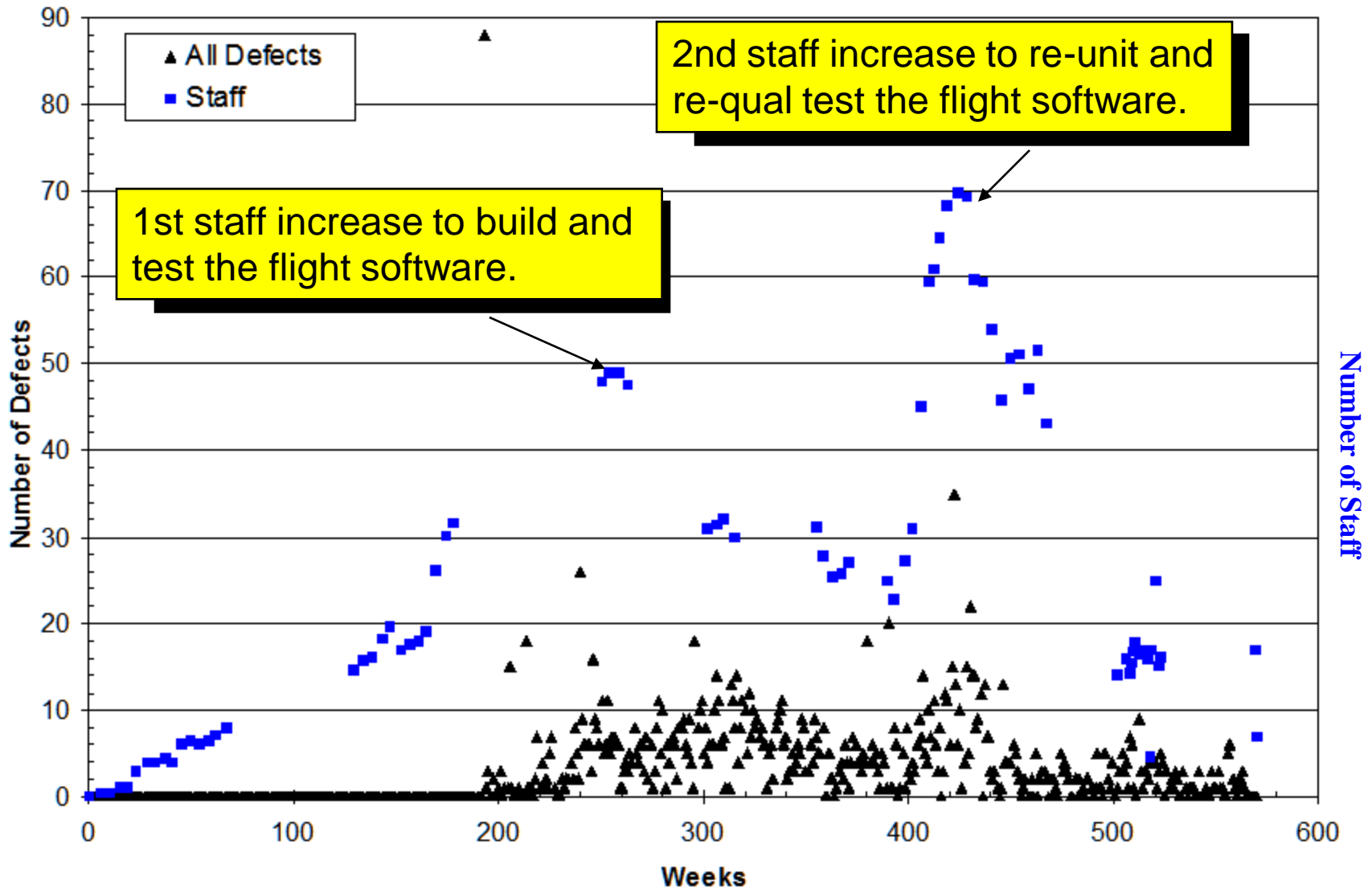
# We Have An Increasing Availability Of Data

## Project A has the Manpower Increase

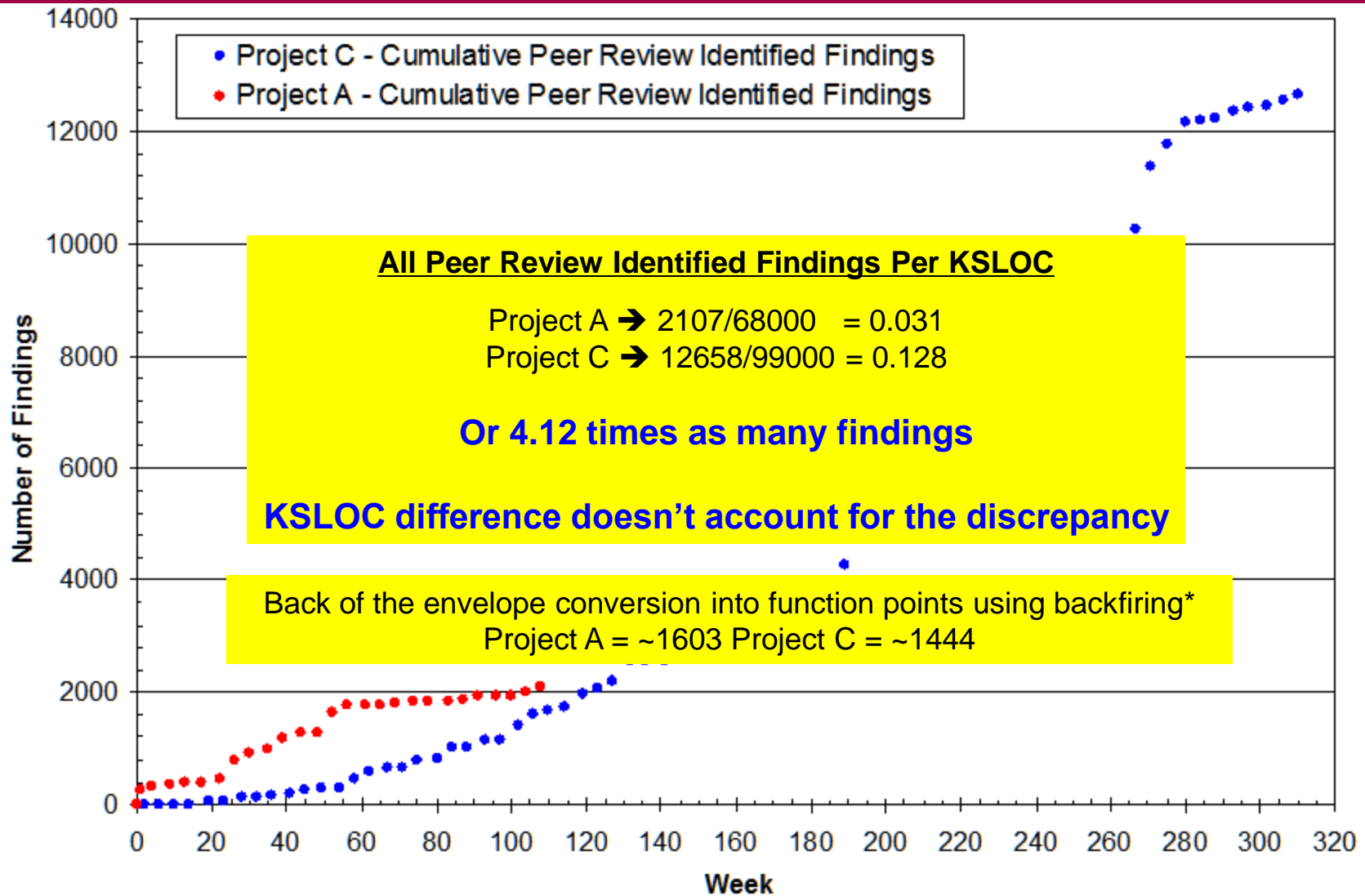


CDF is Cumulative Distribution Function

# Project A – Quantitative Data Example



# Difference Between Projects A and C Cumulative Peer Review Findings



\* R.D. Stutzke, *Estimating Software-Intensive Systems: Projects, Products, Processes*, Addison-Wesley, 2005: pgs 235, 236.

# Qualitative Observations of Project A










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- **Tight budget environment with high schedule pressure and no initial government oversight/insight of the development effort**
- **A degree of reuse from an internal research project and some COTS (Commercial Off The Shelf) software**
- **Did not formally use a design language to do anything other than provide the government with their required design documents**
- **Aerospace identified a lack of both peer review thoroughness, and unit and qualification test rigor leading to heavy government oversight into a mandated re-unit and re-qualification testing effort**

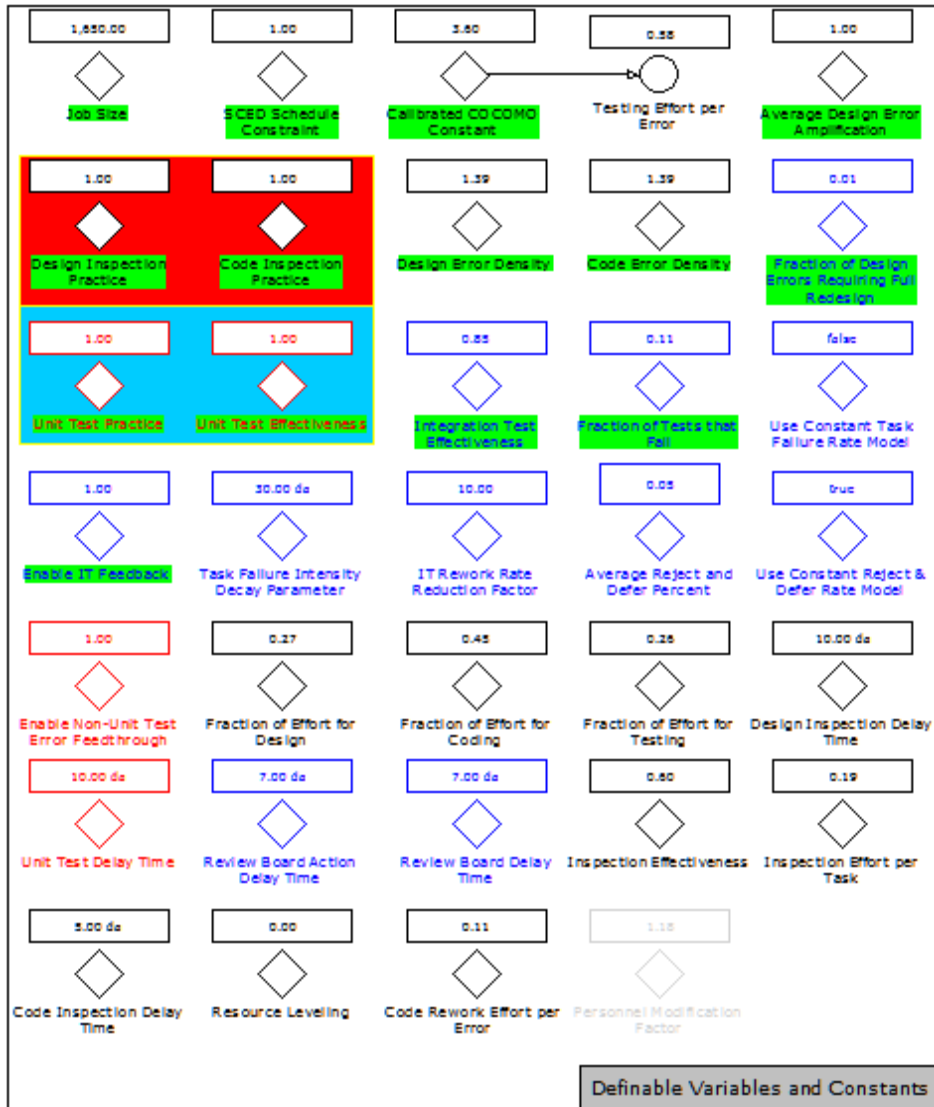
# System Dynamics Modeling Approach

- **Used Ray Madachy's inspection-based system dynamics model (referring to this new model as the Modified Madachy Model) as the basis**
  - ❖ Re-implemented a 1-for-1 inspection-based model in the Powersim tool (Madachy used iThink) without modifications
    - Obtained results that closely match between the Powersim implementation and Madachy's iThink implementation using test cases from his Ph.D. dissertation
- **Incrementally added the following (and the ability to disable each)**
  - ❖ A sub-model for unit testing using his approach for an inspection model
  - ❖ Added an Integration testing (IT) feedback loop model
- **Created a large test matrix to investigate some “*What If*” scenarios using the modified model's unit test and integration test feedback loops enabled**

# System Dynamics Modeling Symbols

Symbol	Name	Description
	Level	A variable that accumulates changes, which are influenced by in and/or out flows.
	Reservoir	A special type of level that cannot be depleted below zero.
	Auxiliary	A variable that contains calculations based on other variables.
	Constant	A variable that contains a fixed (initial) value.
	Continuous flow with attached auxiliary	A continuous flow connector with an attached auxiliary variable.
	Information link	A connector that provides information to auxiliaries about the value of other variables.
	Delayed link	A connector that provides delayed information to auxiliaries about the value of other variables at an earlier stage in the simulation.
	Initialization link	A connector that provides start-up (initial) information to variables (both auxiliaries and levels) about the value of other variables.
	Cloud	A symbol illustrating an undefined source or outlet for a flow to or from a level. The cloud symbol, also referred to as the source or sink of a flow, indicates the model's outer limits.

# Modeling 'Knobs'



## Model "knobs" and model color coding

**Black** symbols are from the original Madachy inspection-based model

**Red** symbols are the Unit Testing additions

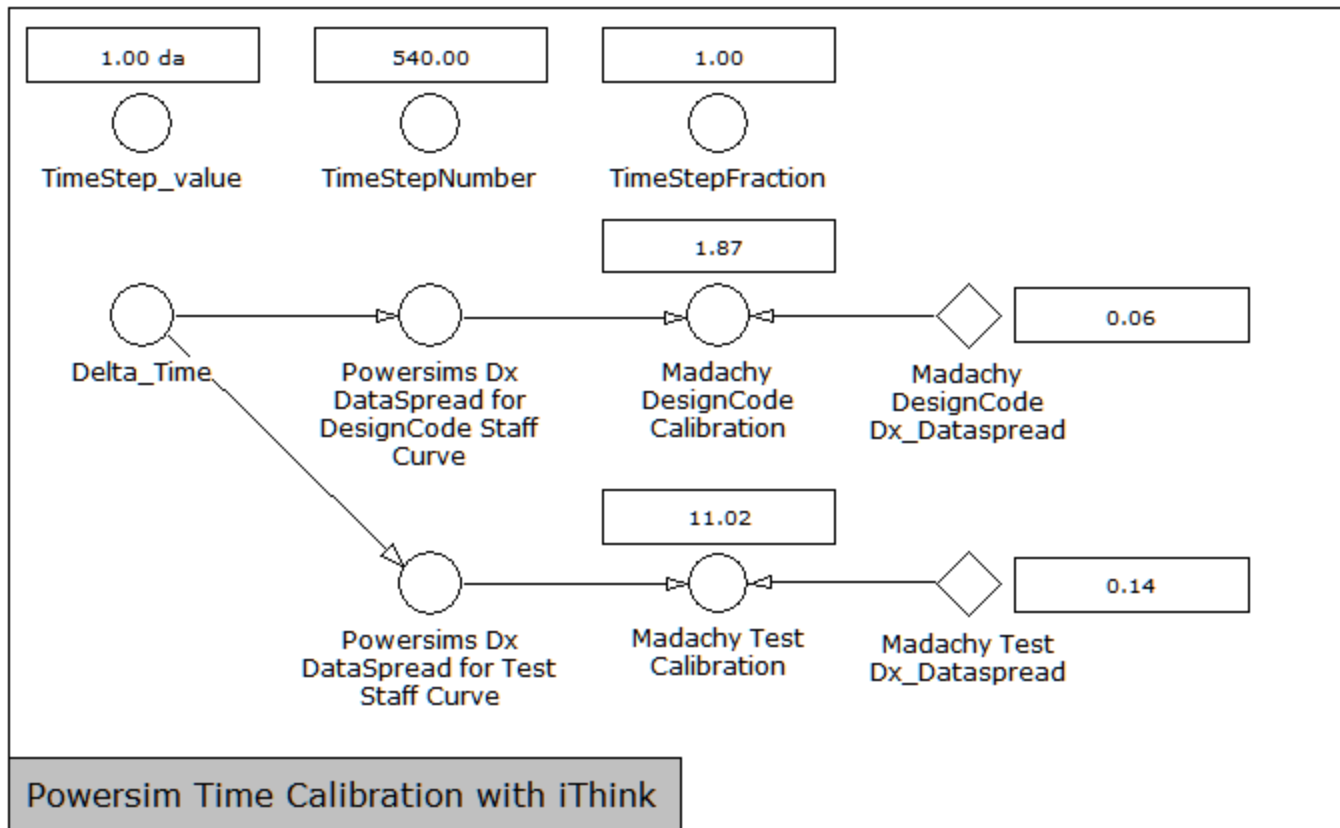
**Blue** symbols are the Integration Test feedback additions

**Grey** symbols are for Processing Staff Curves

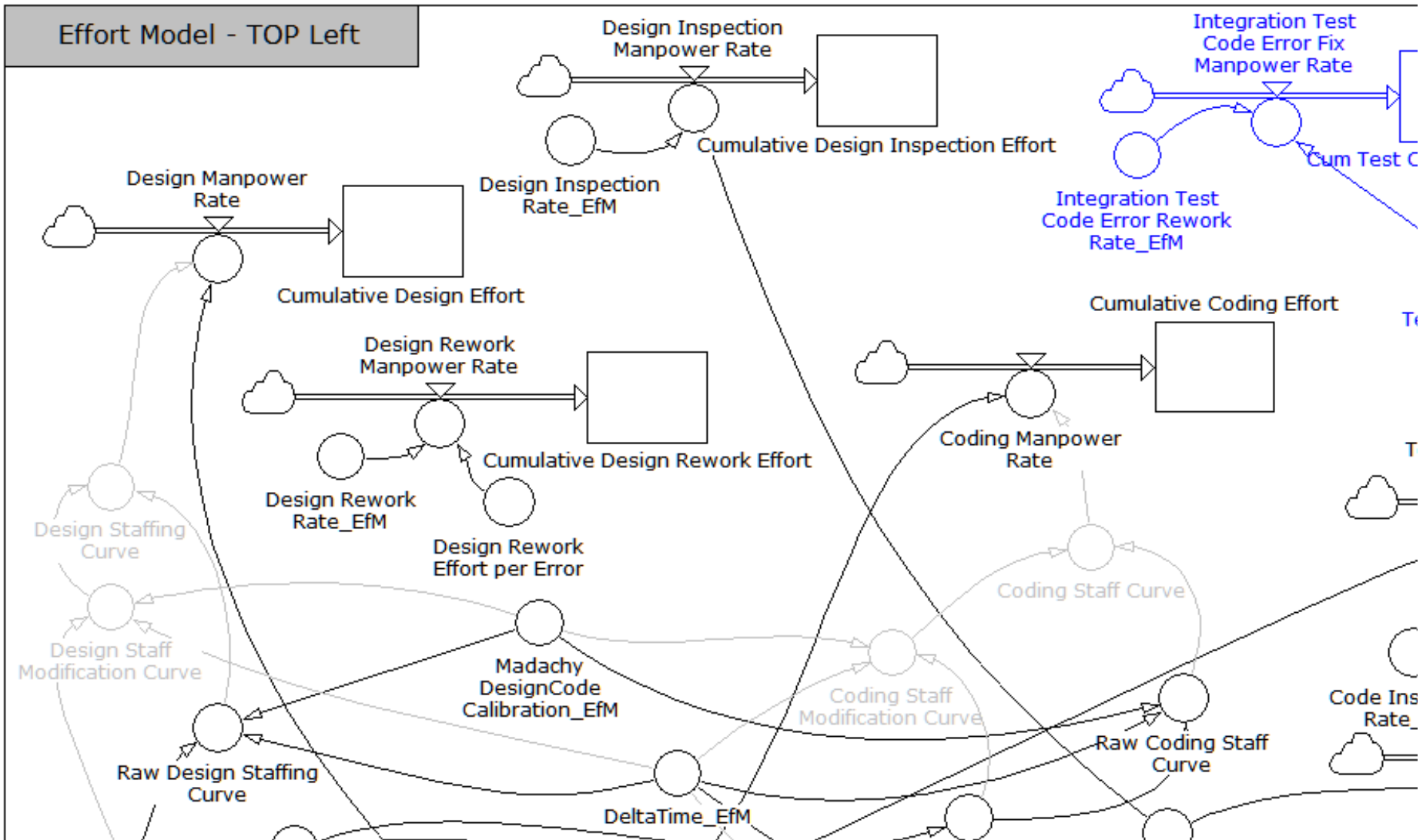
Symbols with **Red** and **L-Blue** backgrounds were modified frequently when model testing

Symbols with **B-Green** background behind the text are modified infrequently during model testing

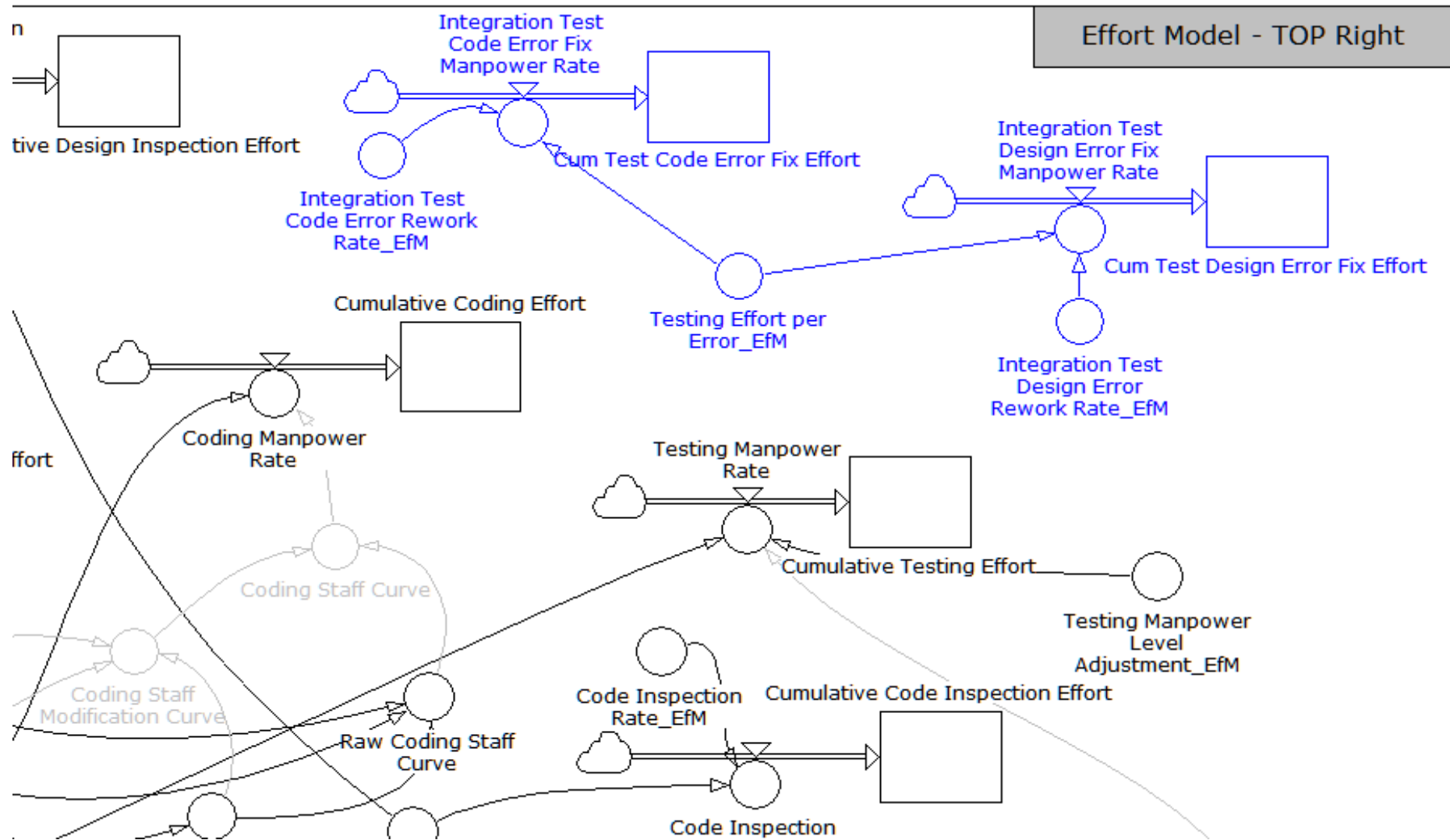
# Powersim/iThink Model Calibration



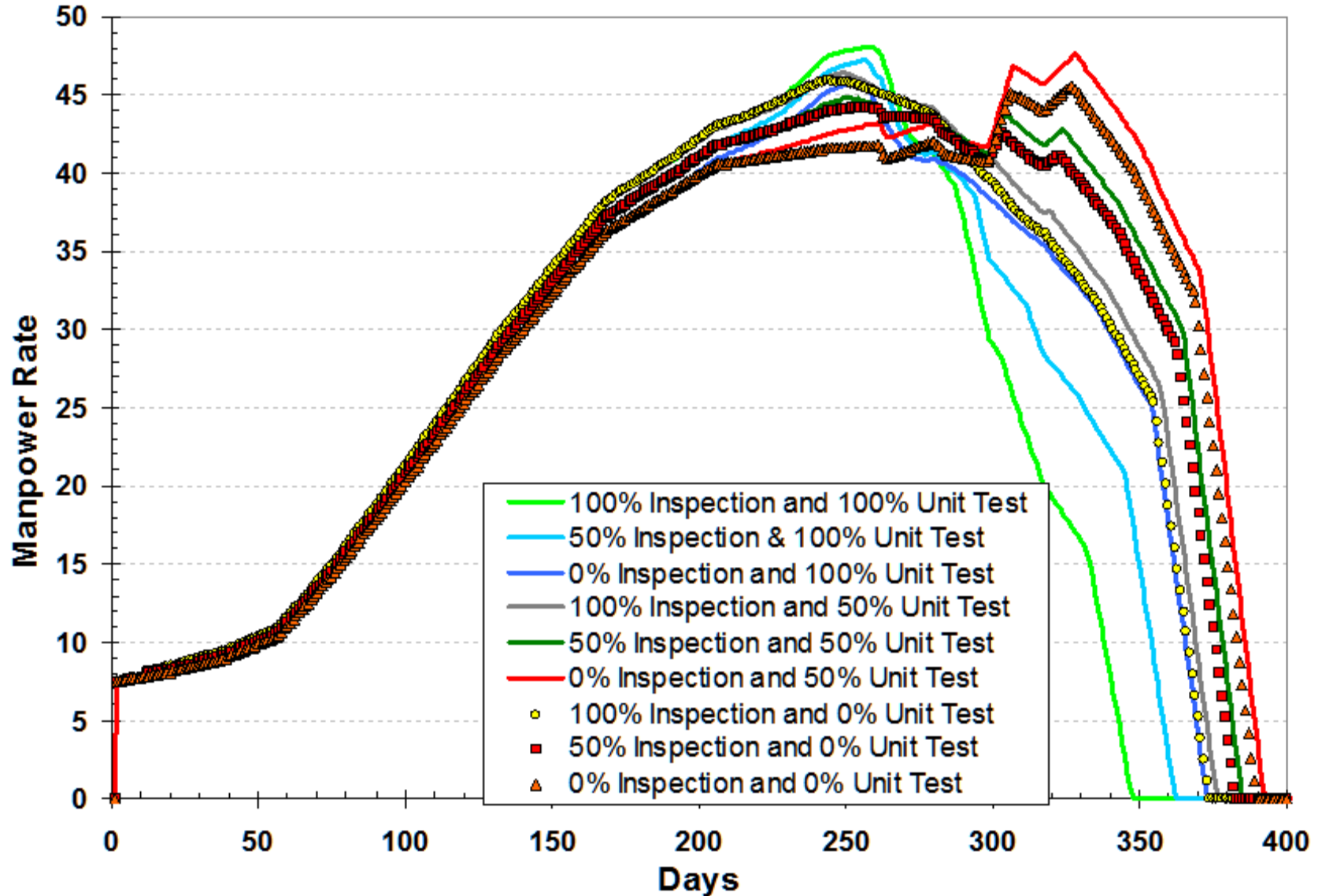
# Effort Model – TOP Left



# Effort Model – TOP Right



# Modeling Results Using Madachy's Staff Curves



# Summary of Findings

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- **Unit testing adds up-front development effort but can reduce the overall development time**
- **Model predicts a manpower increase ‘spike’ from a lack of up-front unit testing and inspections**
  - ❖ The base Madachy Inspection Model does not have a second effort spike
  - ❖ Real data supports the existence of this second effort spike

# Future Work Should...

- **Better model for parallel code and design reverse engineering that our contractors appear to favor**
- **Include other testing efforts as unique feedback loops**
- **Add Orthogonal Defect Classification (ODC) splitting of defects found by the various test methods**
- **Operational use feedback effects**
- **Use COCOMO II as the modeling basis**
  - ❖ Redefine the model to include effort on staff actually doing (e.g. documentation) and account for the defect flows between these artifacts and into the final code (system spec → software spec → software design → software code)
    - I actually started down this path – but decided to punt in order to keep the number of changes between the base Madachy Inspection Model and the Modified Madachy Model at a manageable number

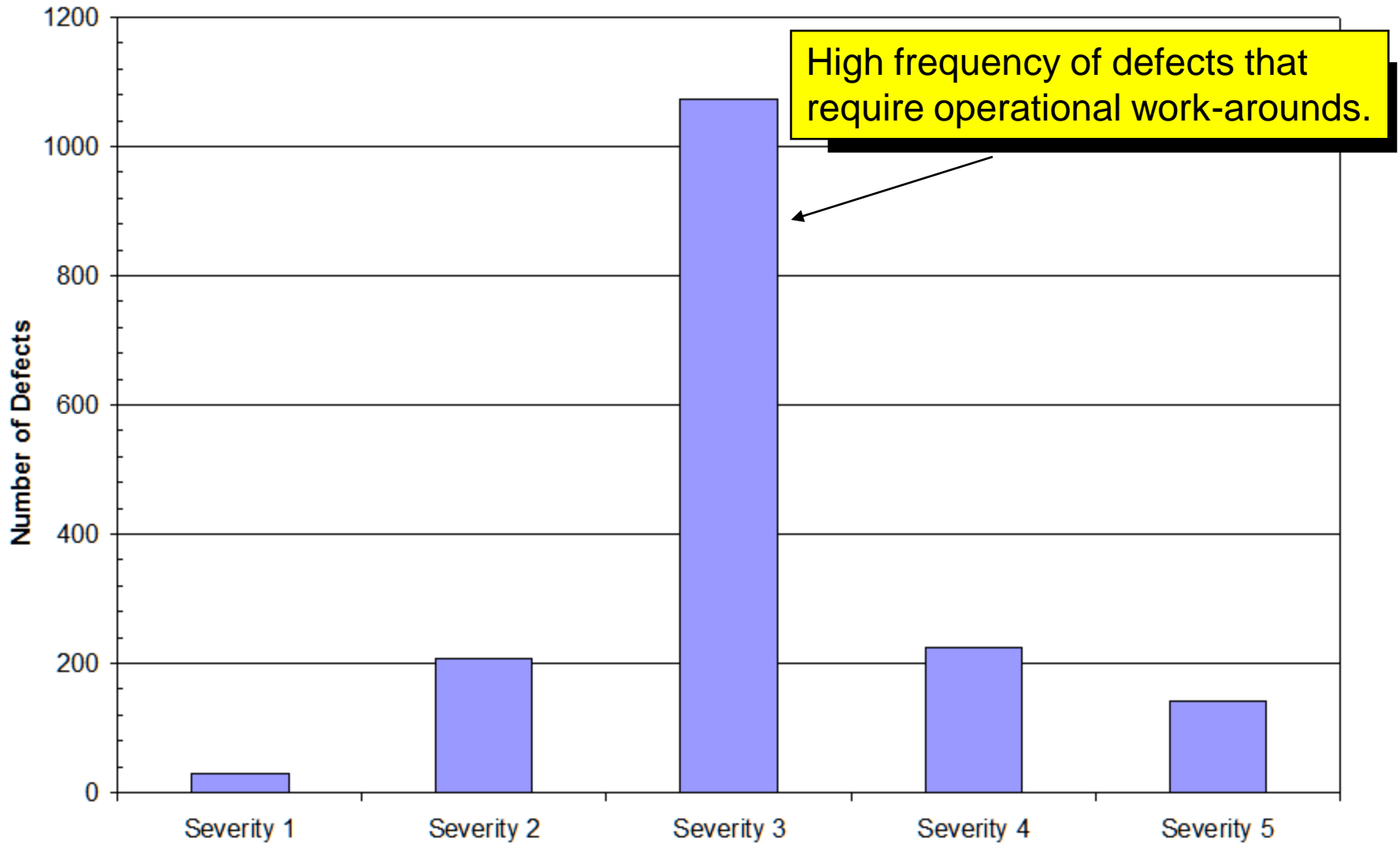
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# BACKUP

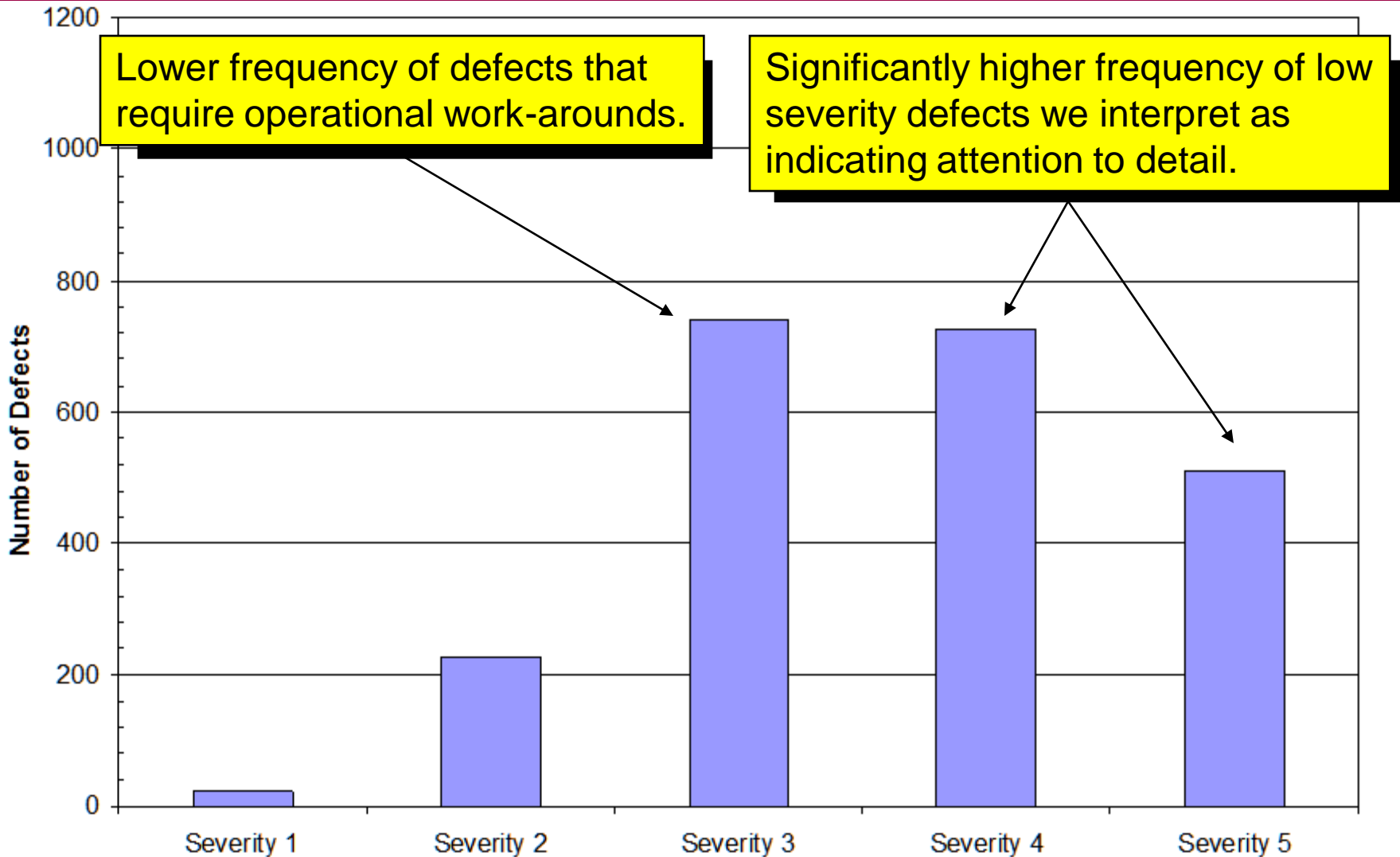
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# Supporting Quantitative Data

# Project A - Defect Severity Frequencies



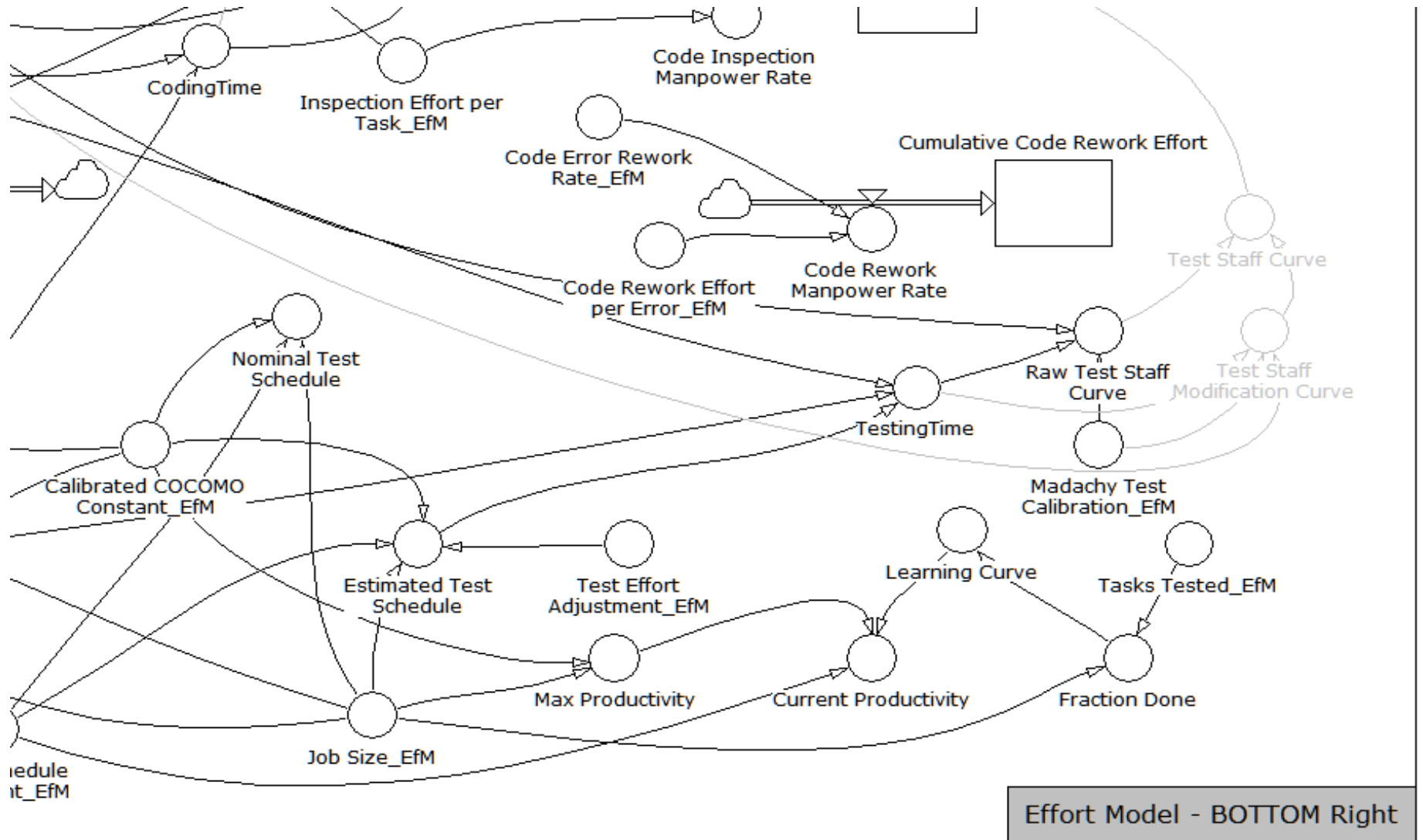
# Project C - Defect Severity Frequencies



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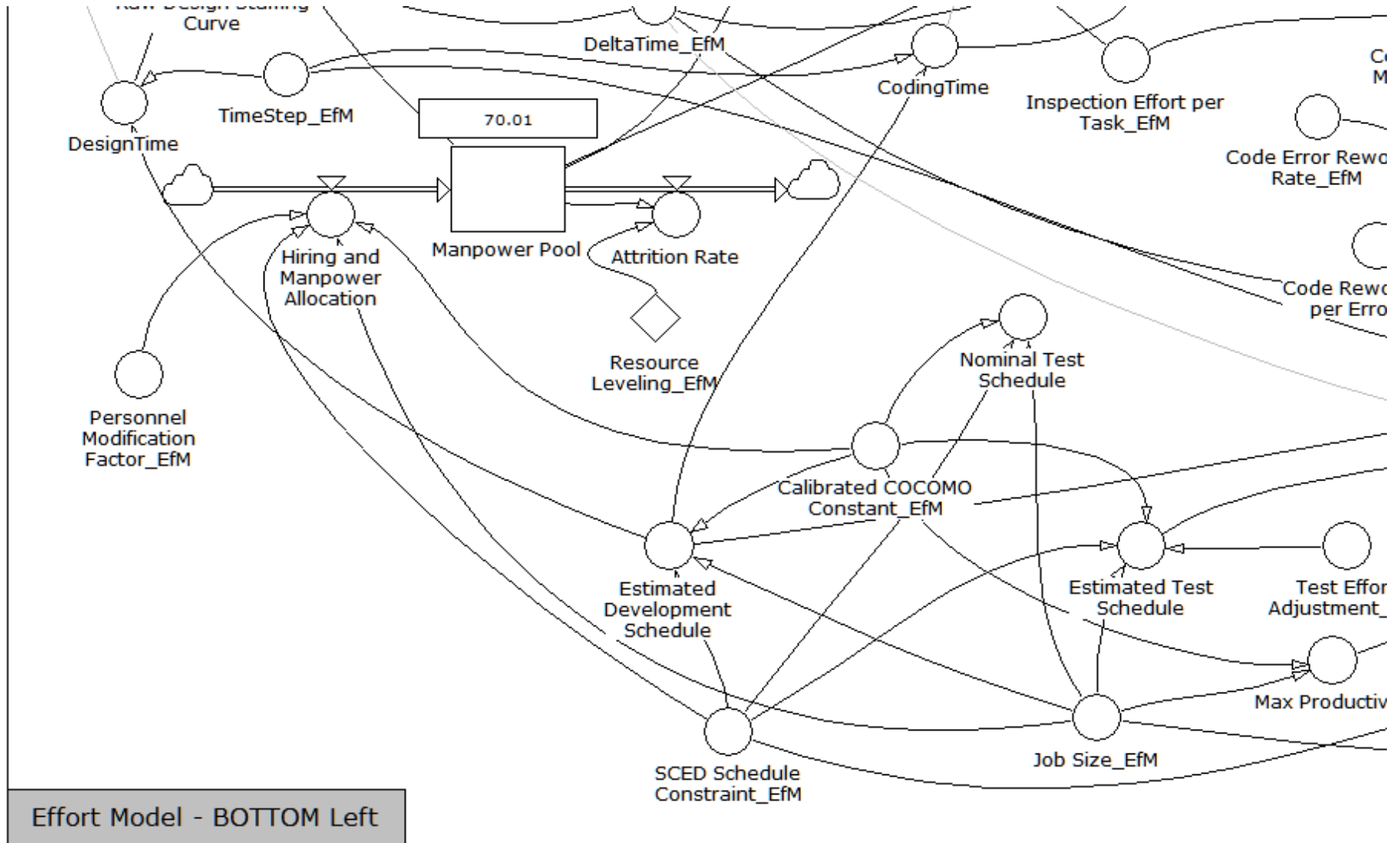
# **A System Dynamics Model with Unit Test and Integration Test Feedback**

# Effort Model – BOTTOM Right



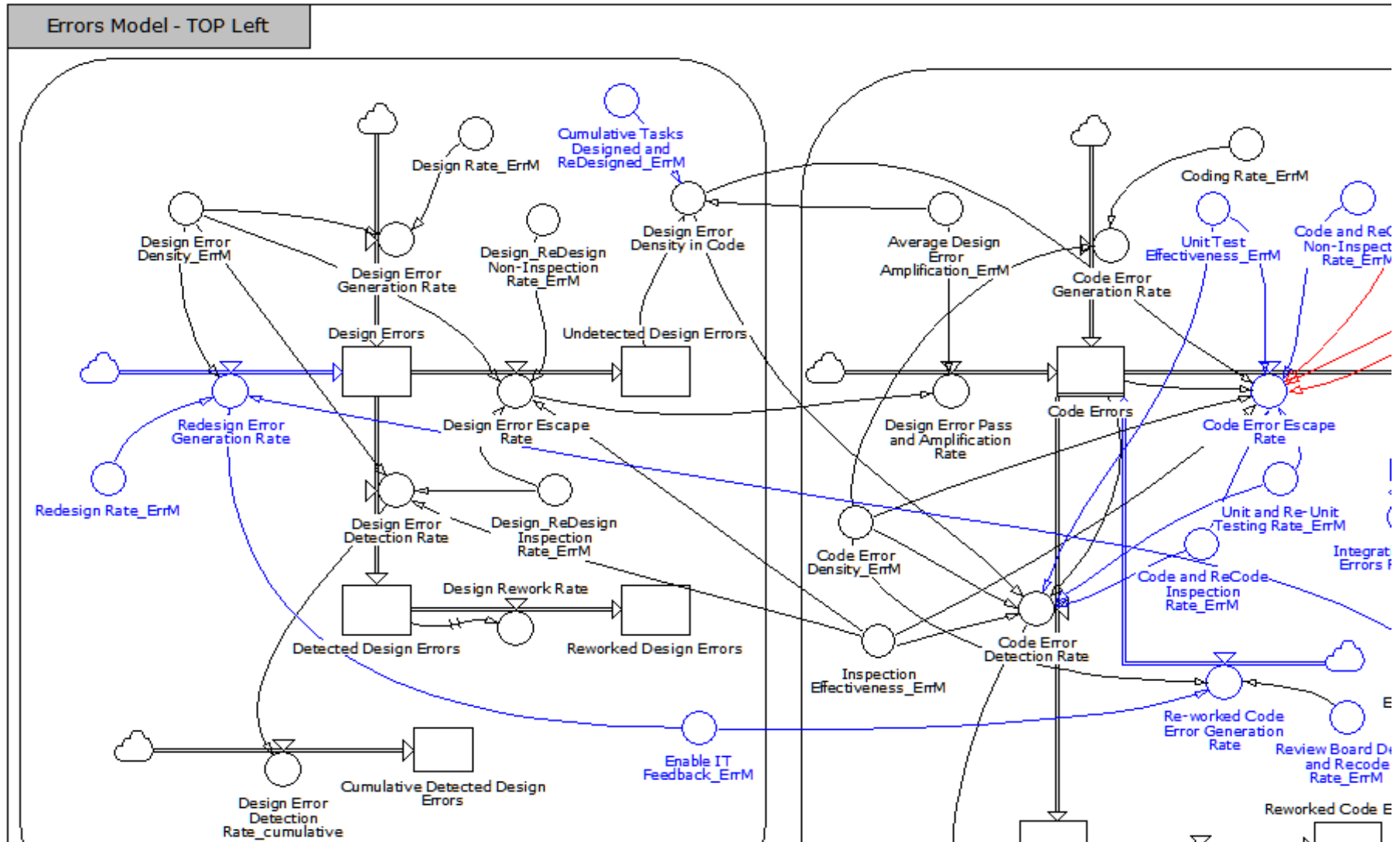
Effort Model - BOTTOM Right

# Effort Model – BOTTOM Left



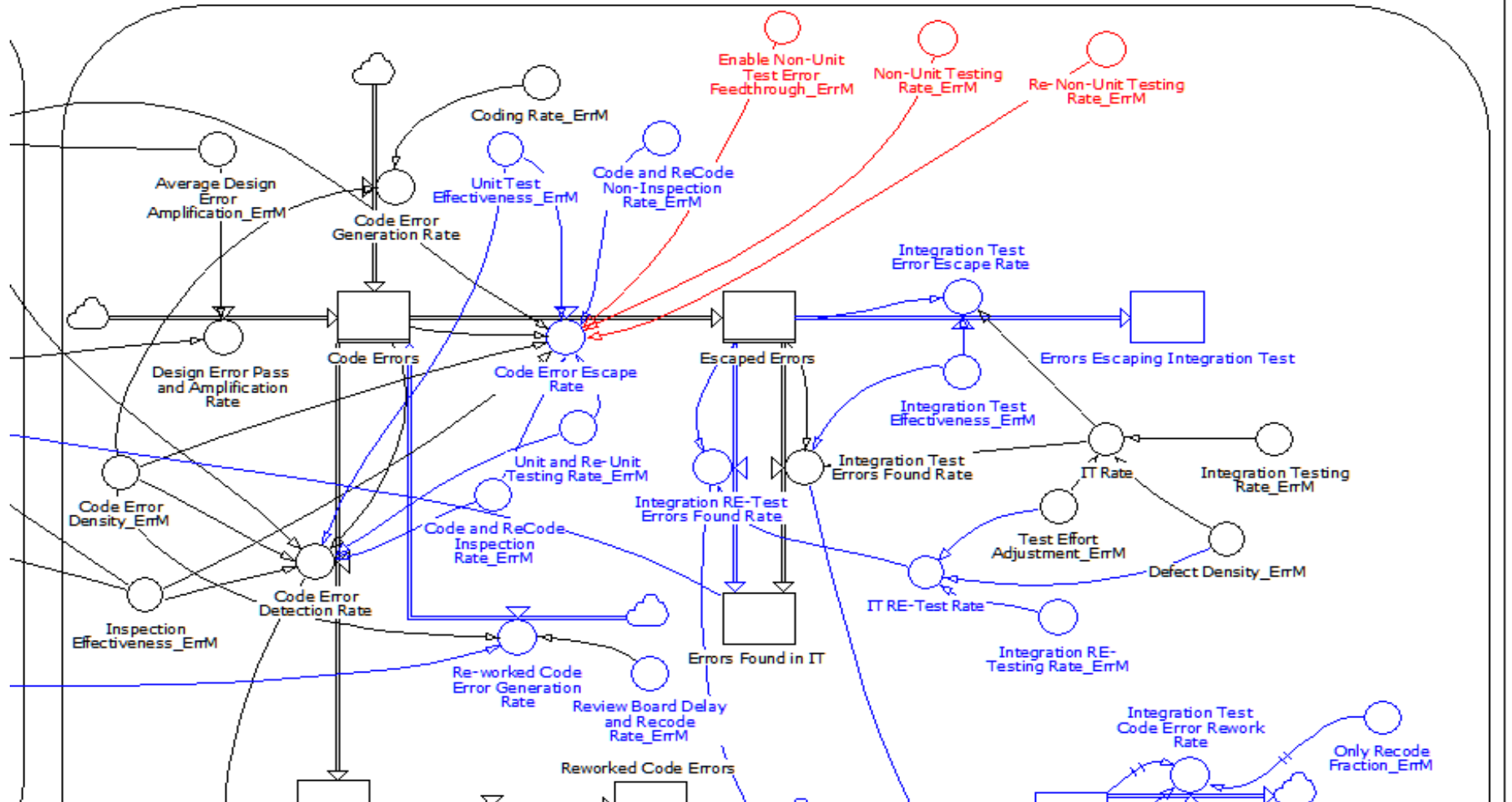
Effort Model - BOTTOM Left

# Errors Model – TOP Left

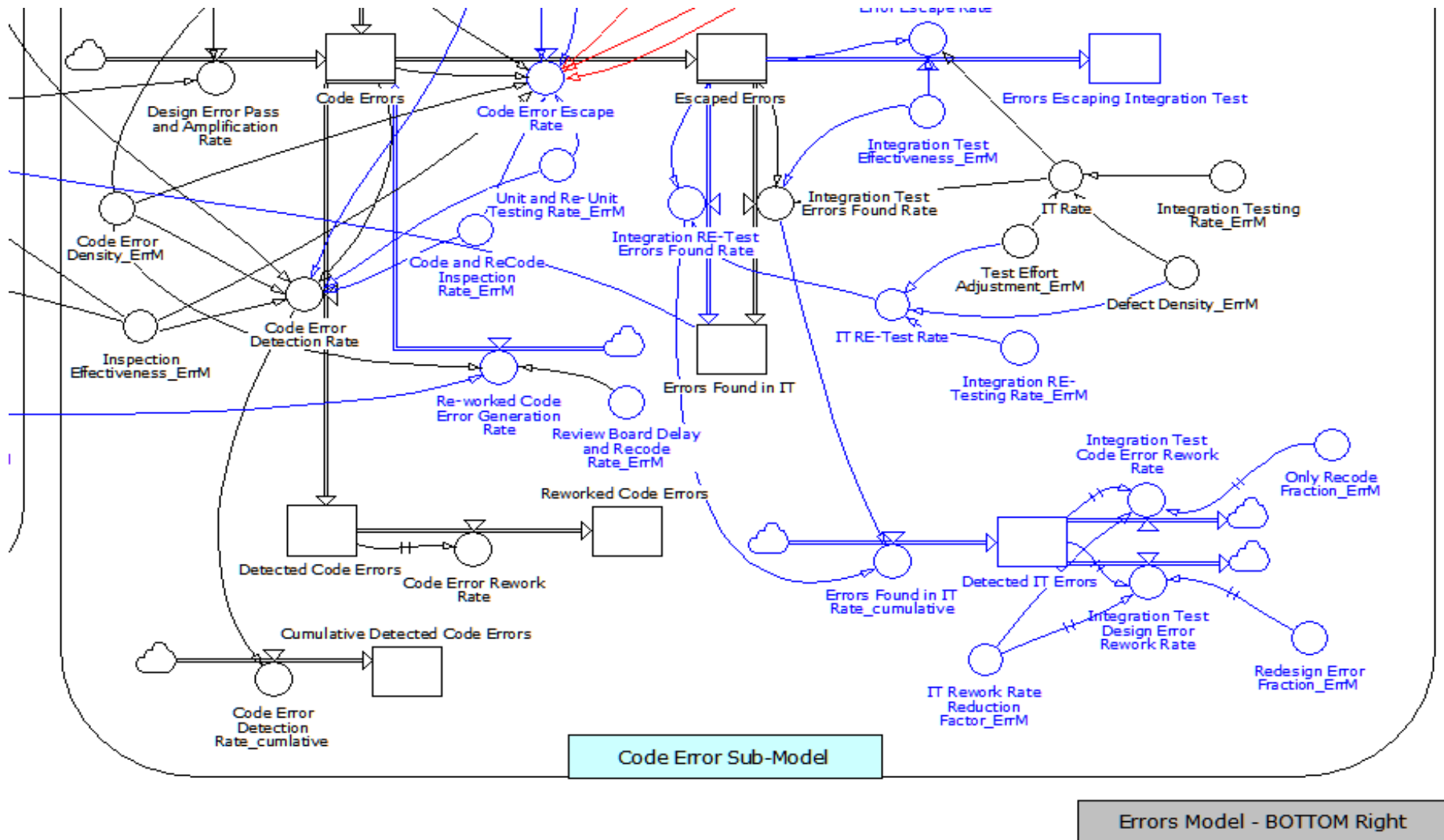


# Errors Model – TOP Right

Errors Model - TOP Right

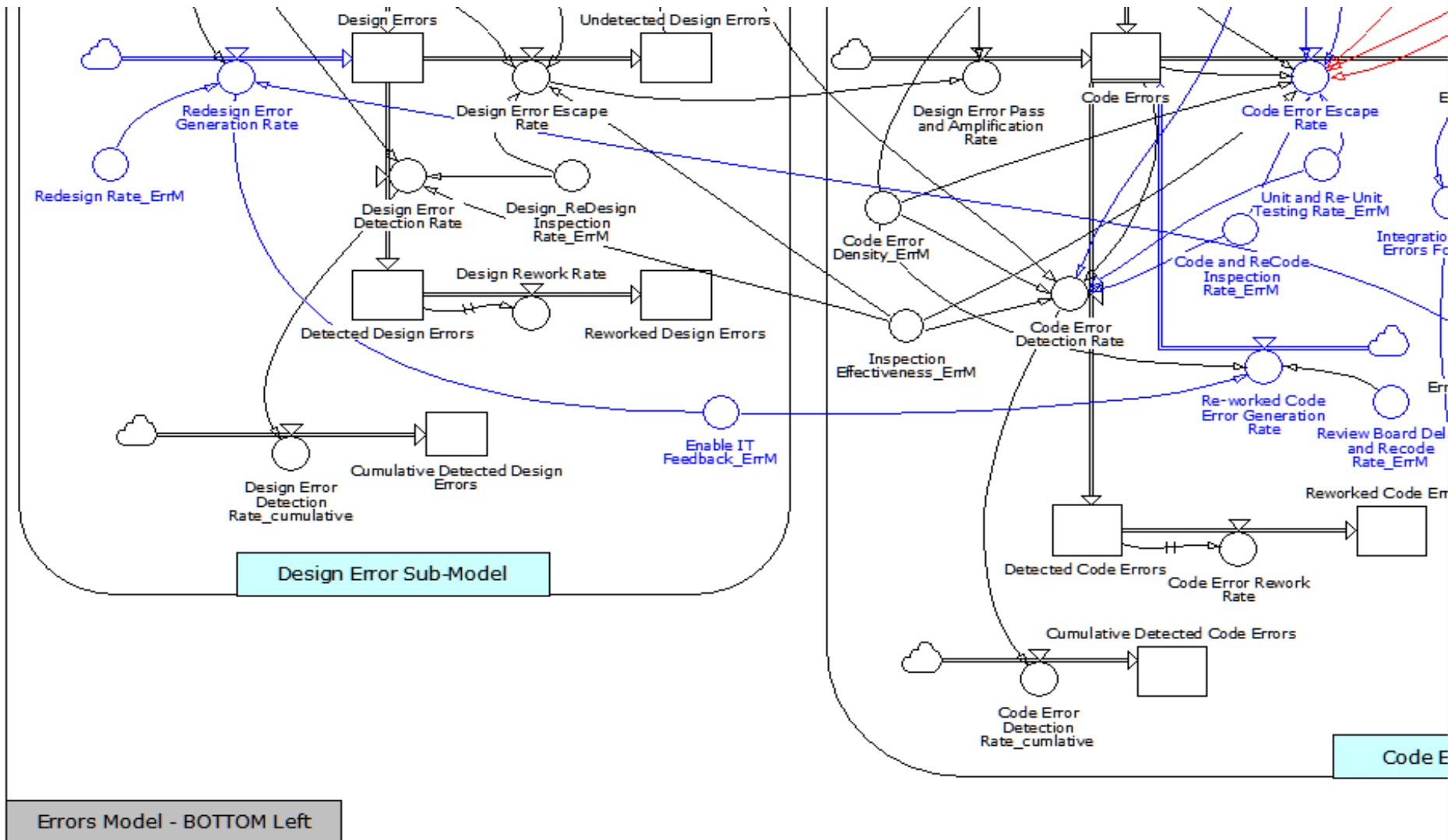


# Errors Model – BOTTOM Right

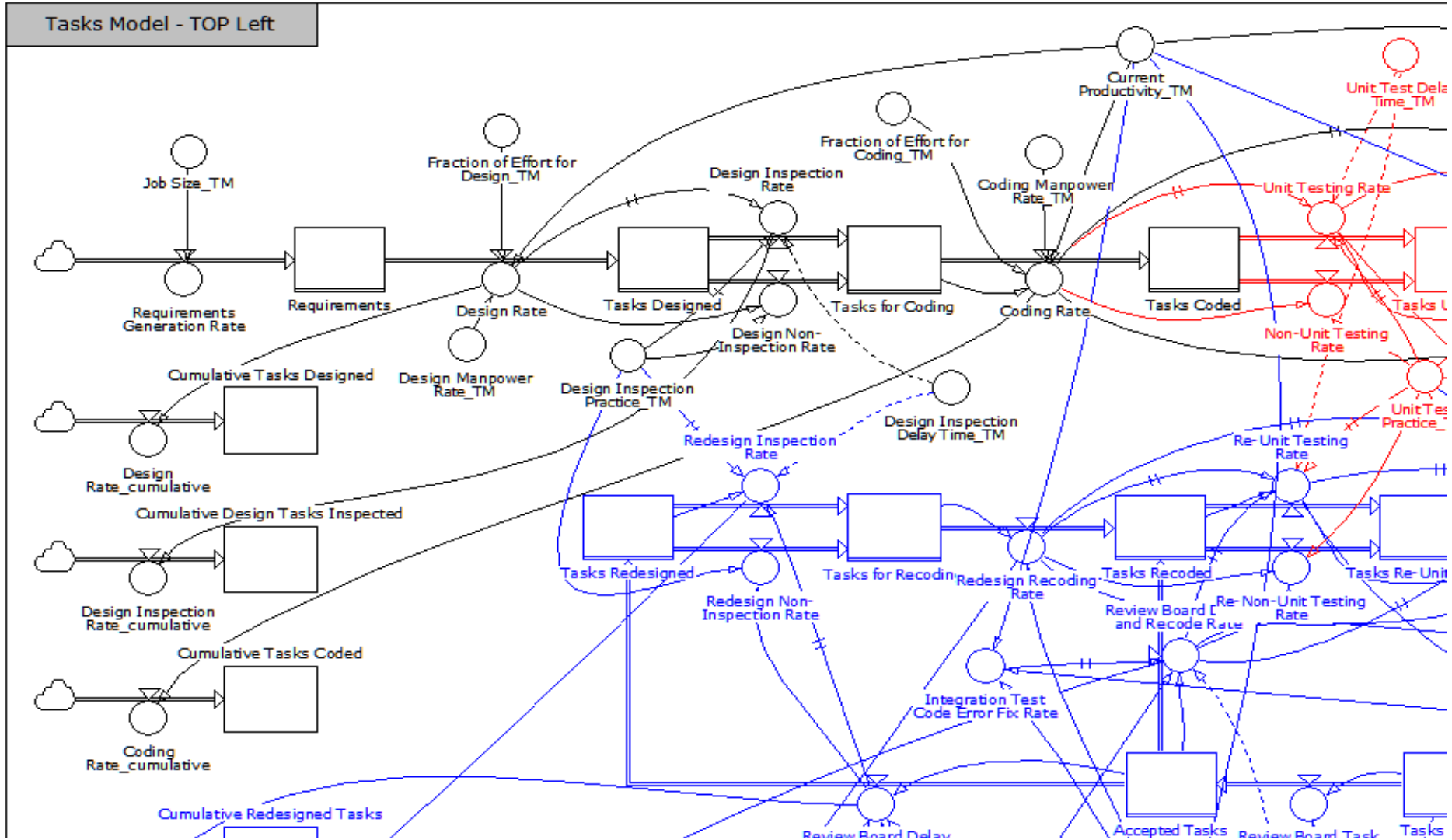


Errors Model - BOTTOM Right

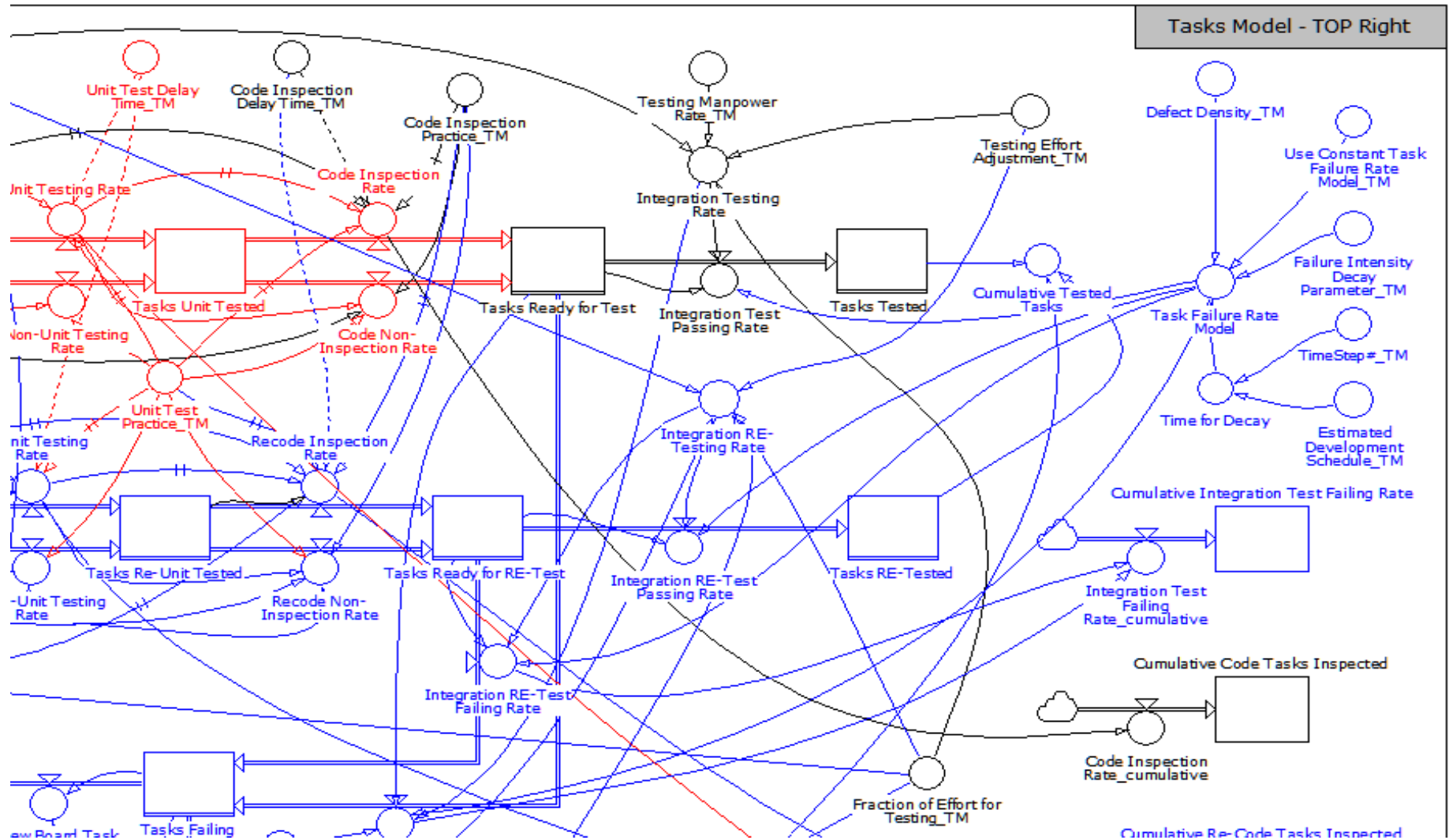
# Errors Model – BOTTOM Left



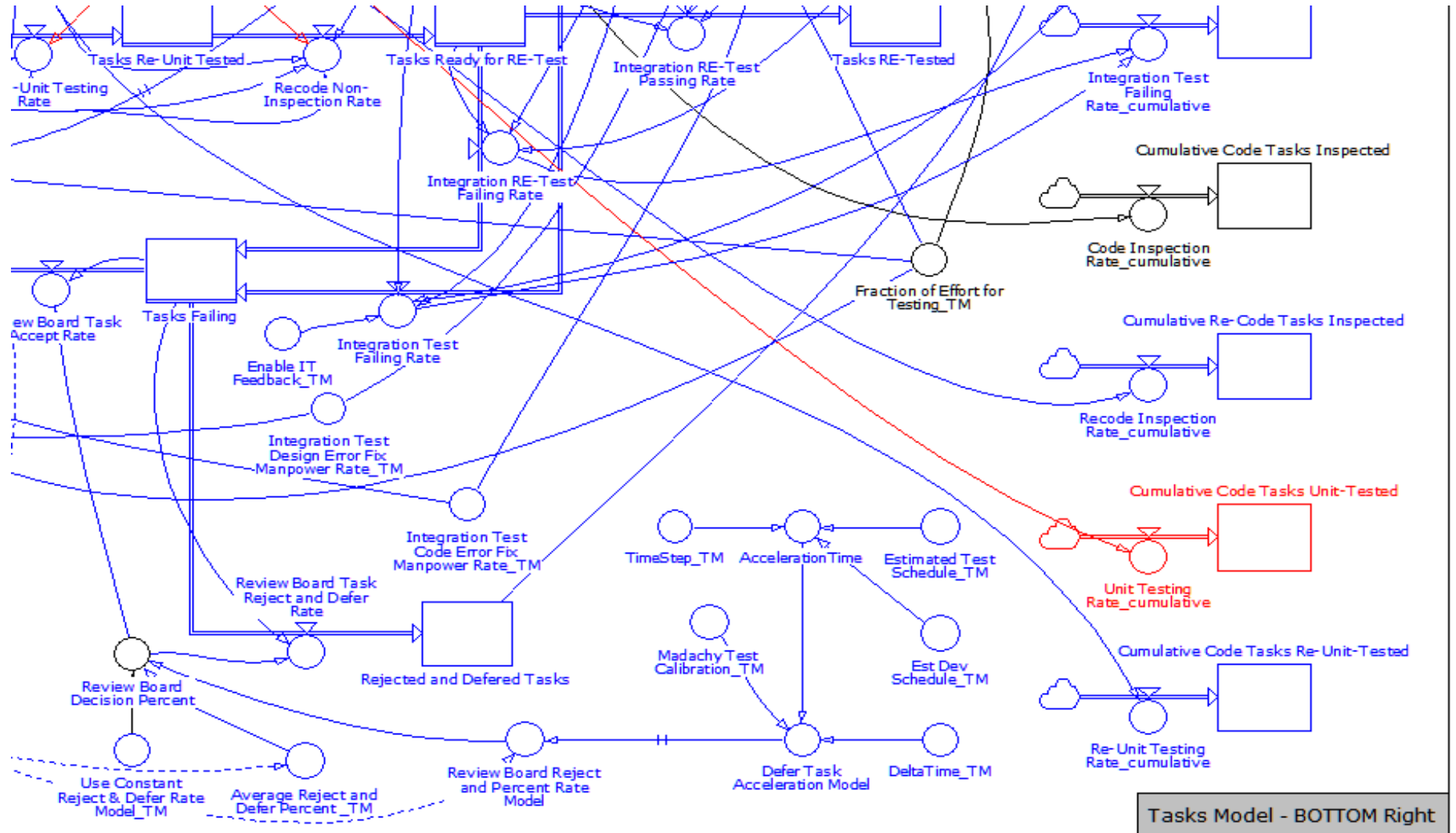
# Tasks Model – TOP Left



# Tasks Model – TOP Right

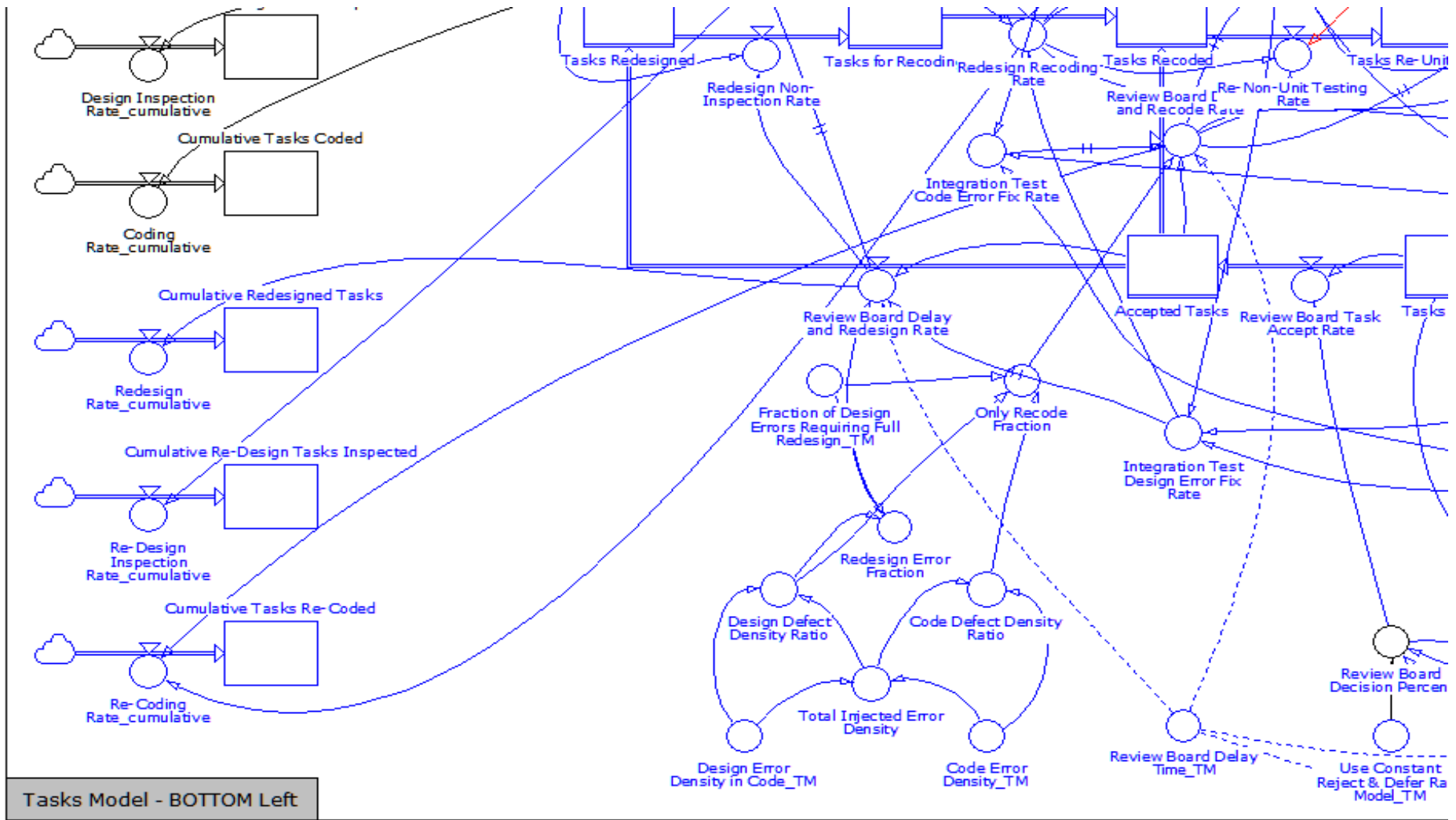


# Tasks Model – BOTTOM Right



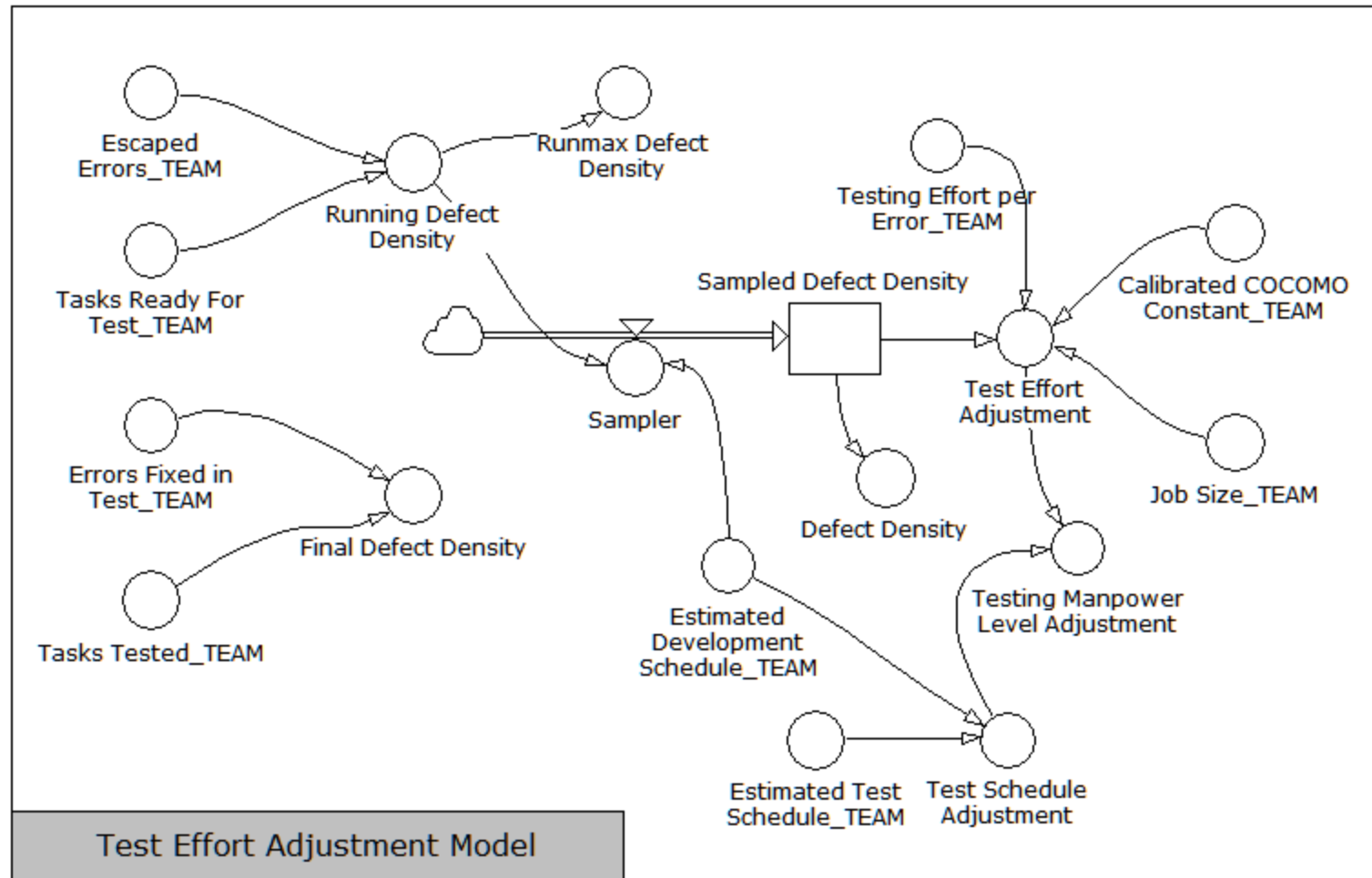
Tasks Model - BOTTOM Right

# Tasks Model – BOTTOM Left

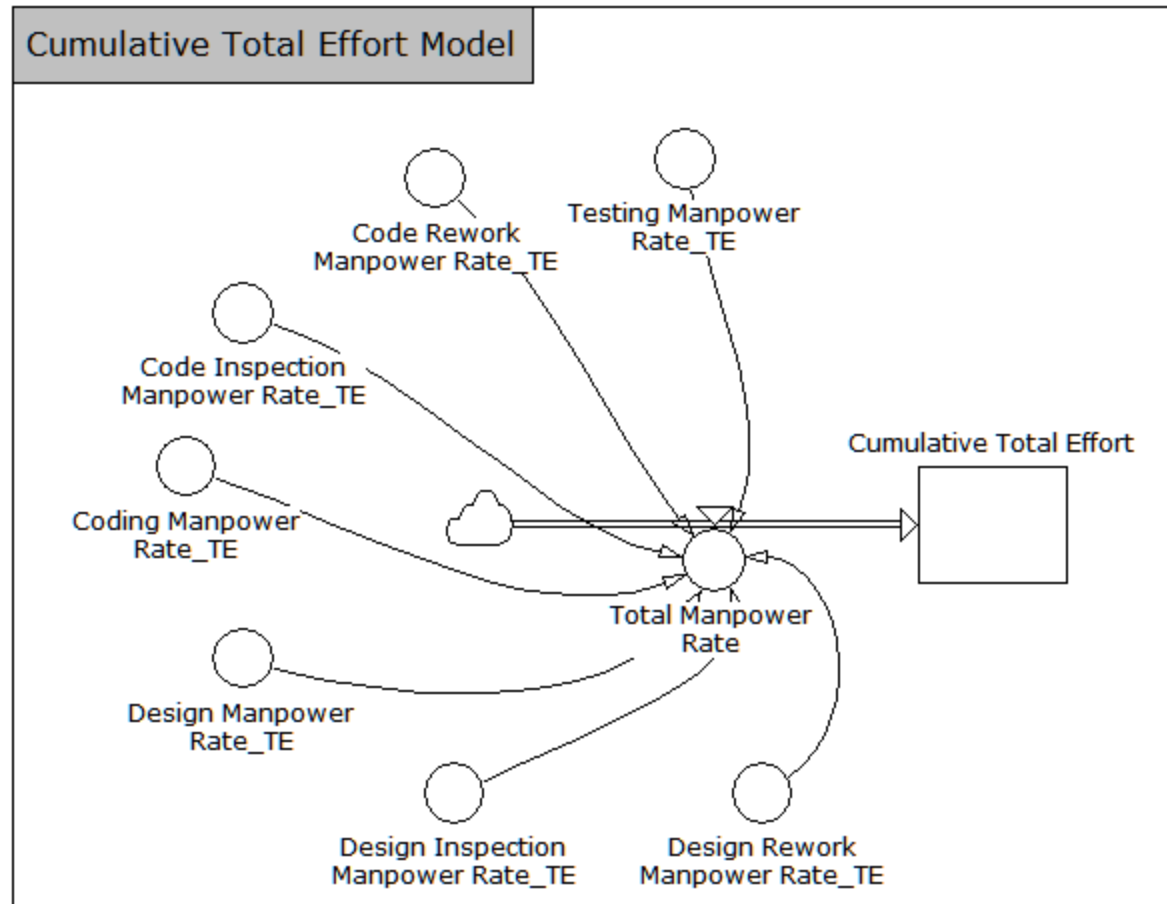


Tasks Model - BOTTOM Left

















# Test Effort Adjustment Model






# Cumulative Total Effort Model



# Constants, Variables and Equations

 Attrition Rate	$\text{IF}(\text{Resource Leveling\_Efm} > 0, \text{PULSE}(\text{Manpower Pool} * (1 - \text{Resource Leveling\_Efm}), \text{STARTTIME} + 999 * \text{TIMESTEP}, 999 * \text{TIMESTEP}), 0 * \text{PULSE}(\text{Manpower Pool} * (1 - \text{Resource Leveling\_Efm}), \text{STARTTIME} + 999 * \text{TIMESTEP}, 999 * \text{TIMESTEP}))$
 Average Design Error Amplification	1.0
 Average Design Error Amplification_ErrM	'Average Design Error Amplification'
 Calibrated COCOMO Constant	3.6
 Calibrated COCOMO Constant_Efm	'Calibrated COCOMO Constant'
 Calibrated COCOMO Constant_TEAM	'Calibrated COCOMO Constant'
 Code Error Density	1.5
 Code Error Density_ErrM	'Code Error Density'
 Code Error Detection Rate	$\text{MIN}((\text{'Code Error Density\_ErrM'} + \text{'Design Error Density in Code'}) * (\text{'Code Inspection Rate\_ErrM'} * \text{'Inspection Efficiency\_ErrM'} + \text{'Unit Testing Rate\_ErrM'} * \text{'Unit Test Efficiency\_ErrM'}), \text{'Code Errors'} / \text{TIMESTEP})$
 Code Error Detection Rate_cumulative	'Code Error Detection Rate'
 Code Error Escape Rate	$\text{MIN}((\text{'Code Error Density\_ErrM'} + \text{'Design Error Density in Code'}) * (\text{'Code Inspection Rate\_ErrM'} * (1 - \text{'Inspection Efficiency\_ErrM'}) + \text{'Unit Testing Rate\_ErrM'} * (1 - \text{'Unit Test Efficiency\_ErrM'}) + \text{'Code Non-Inspection Rate\_ErrM'}), \text{'Code Errors'} / \text{TIMESTEP})$
 Code Error Generation Rate	'Code Error Density\_ErrM' * Coding Rate_ErrM'
 Code Errors	0
 Code Error Detection Rate.out	'Code Error Detection Rate'
 Code Error Escape Rate.out	'Code Error Escape Rate'
 Code Error Generation Rate.in	'Code Error Generation Rate'
 Design Error Pass and Amplification Rate.in	'Design Error Pass and Amplification Rate'
 Re-worked Code Error Generation Rate.in	'Re-worked Code Error Generation Rate'
 Code Inspection Delay Time	10 <<da>>
 Code Inspection Delay Time_TM	'Code Inspection Delay Time'
 Code Inspection Manpower Rate	'Code Inspection Rate_Efm' * Inspection Effort per Task_Efm'
 Code Inspection Manpower Rate_TE	'Code Inspection Manpower Rate'
 Code Inspection Practice	1
 Code Inspection Practice_TM	'Code Inspection Practice'
 Code Inspection Rate	$\text{DELAYPPL}(\text{'Code Inspection Practice\_TM'} * (\text{'Unit Testing Rate'} + (1 - \text{'Unit Test Practice\_TM'}) * \text{'Coding Rate'}), \text{'Code Inspection Delay Time\_TM'})$
 Code Inspection Rate_cumulative	'Code Inspection Rate'
 Code Inspection Rate_Efm	'Code Inspection Rate'
 Code Inspection Rate_ErrM	'Code Inspection Rate'

# Constants, Variables and Equations

 Code Non-Inspection Rate	IF('Unit Test Practice_TM'=0 AND 'Code Inspection Practice_TM'=0,'Coding Rate',(1-'Code Inspection Practice_TM')*Unit Testing Rate')
 Code Non-Inspection Rate_ErrM	'Code Non-Inspection Rate'
 Code Rework Effort per Error	0.11
 Code Rework Effort per Error_EfM	'Code Rework Effort per Error'
 Code Rework Manpower Rate	'Code Rework Rate_EfM'*Code Rework Effort per Error_EfM'
 Code Rework Manpower Rate_TE	'Code Rework Manpower Rate'
 Code Rework Rate	MIN(DELAYPPL('Detected Code Errors'/10,7*TIMESTEP)/TIMESTEP,'Detected Code Errors'/TIMESTEP)
 Code Rework Rate_EfM	'Code Rework Rate'
 Coding Manpower Rate	'Manpower Pool'*Coding Staff Curve'/TIMESTEP
 Coding Manpower Rate_TE	'Coding Manpower Rate'
 Coding Manpower Rate_TM	'Coding Manpower Rate'
 Coding Rate	MIN('Coding Manpower Rate_TM'*Current Productivity_TM'/Fraction of Effort for Coding_TM,'Tasks for Coding'/TIMESTEP)
 Coding Rate_cumulative	'Coding Rate'
 Coding Rate_ErrM	'Coding Rate'
 Coding Staff Curve	GRAPH(CodingTime,0,17*DeltaTime_TM*Madachy DesignCode Calibration_EfM',{0,0,0,0,0,0,0,0,0,0,0.085,0.297,0.720,1.0,0.860,0.551,0.127,0})
 CodingTime	TimeStep_TM/(0.85*Estimated Development Schedule')
 Cumulative Code Inspection Effort	0
 Code Inspection Manpower Rate.in	'Code Inspection Manpower Rate'
 Cumulative Code Rework Effort	0
 Code Rework Manpower Rate.in	'Code Rework Manpower Rate'
 Cumulative Code Tasks Inspected	0
 Code Inspection Rate_cumulative.in	'Code Inspection Rate_cumulative'
 Cumulative Coding Effort	0
 Coding Manpower Rate.in	'Coding Manpower Rate'
 Cumulative Design Effort	0
 Design Manpower Rate.in	'Design Manpower Rate'
 Cumulative Design Inspection Effort	0
 Design Inspection Manpower Rate.in	'Design Inspection Manpower Rate'
 Cumulative Design Rework Effort	0
 Design Rework Manpower Rate.in	'Design Rework Manpower Rate'

# Constants, Variables and Equations

Cumulative Design Tasks Inspected	0
+ Design Inspection Rate_cumulative.in	'Design Inspection Rate_cumulative'
Cumulative Detected Code Errors	0
+ Code Error Detection Rate_cumulative.in	'Code Error Detection Rate_cumulative'
Cumulative Detected Design Errors	0
+ Design Error Detection Rate_cumulative.in	'Design Error Detection Rate_cumulative'
Cumulative Tasks Coded	0
+ Coding Rate_cumulative.in	'Coding Rate_cumulative'
Cumulative Tasks Designed	0.001
+ Design Rate_cumulative.in	'Design Rate_cumulative'
Cumulative Tasks Designed_ErrM	'Cumulative Tasks Designed'
Cumulative Test Error Fix Effort	0
+ Integration Test Error Fix Manpower Rate.in	'Integration Test Error Fix Manpower Rate'
Cumulative Testing Effort	0
+ Testing Manpower Rate.in	'Testing Manpower Rate'
Cumulative Total Effort	0
+ Total Manpower Rate.in	'Total Manpower Rate'
Current Productivity	'Max Productivity'*'Learning Curve'/(100/'SCED Schedule Constraint_EffM')
Current Productivity_TM	'Current Productivity'
Defect Density	'Sampled Defect Density'
Defect Density_ErrM	'Defect Density'
Delta_Time	TIMESTEP/((STOPTIME-STARTTIME))
DeltaTime_TM	Delta_Time
Design Error Density	1.5
Design Error Density in Code	'Undetected Design Errors'*'Average Design Error Amplification_ErrM'/Cumulative Tasks Designed_ErrM'
Design Error Density_ErrM	'Design Error Density'
Design Error Detection Rate	'Design Inspection Rate_ErrM'*'Design Error Density_ErrM'*'Inspection Efficiency_ErrM'
Design Error Detection Rate_cumulative	'Design Error Detection Rate'
Design Error Escape Rate	'Design Error Density_ErrM'*('Design Inspection Rate_ErrM'*(1-'Inspection Efficiency_ErrM')+'Design Non-Inspection Rate_ErrM')
Design Error Generation Rate	'Design Rate_ErrM'*'Design Error Density_ErrM'
Design Error Pass and Amplification Rate	'Design Error Escape Rate'*'Average Design Error Amplification_ErrM'

# Constants, Variables and Equations

Design Errors	0
Design Error Detection Rate.out	'Design Error Detection Rate'
Design Error Escape Rate.out	'Design Error Escape Rate'
Design Error Generation Rate.in	'Design Error Generation Rate'
Design Inspection Delay Time	10<<da>>
Design Inspection Delay Time_TM	'Design Inspection Delay Time'
Design Inspection Manpower Rate	'Design Inspection Rate_EfM'*Inspection Effort per Task_EfM'
Design Inspection Manpower Rate_TE	'Design Inspection Manpower Rate'
Design Inspection Practice	1
Design Inspection Practice_TM	'Design Inspection Practice'
Design Inspection Rate	DELAYPPL('Design Inspection Practice_TM'*Design Rate','Design Inspection Delay Time_TM')
Design Inspection Rate_cumulative	'Design Inspection Rate'
Design Inspection Rate_EfM	'Design Inspection Rate'
Design Inspection Rate_ErrM	'Design Inspection Rate'
Design Manpower Rate	'Manpower Pool'*Design Staffing Curve'/Timestep
Design Manpower Rate_TE	'Design Manpower Rate'
Design Manpower Rate_TM	'Design Manpower Rate'
Design Non-Inspection Rate	(1-'Design Inspection Practice_TM')*Design Rate'
Design Non-Inspection Rate_ErrM	'Design Non-Inspection Rate'
Design Rate	'Design Manpower Rate_TM'*Current Productivity_TM'/Fraction of Effort for Design_TM'
Design Rate_cumulative	'Design Rate'
Design Rate_ErrM	'Design Rate'
Design Rework Effort per Error	0.055
Design Rework Manpower Rate	'Design Rework Rate_EfM'*Design Rework Effort per Error'
Design Rework Manpower Rate_TE	'Design Rework Manpower Rate'
Design Rework Rate	DELAYPPL('Detected Design Errors'/10,7*Timestep)/Timestep
Design Rework Rate_EfM	'Design Rework Rate'
Design Staffing Curve	GRAPH(DesignTime,0,17*DeltaTime_TM*Madachy DesignCode Calibration_EfM',{0.18,0.195,0.215,0.25,0.345,0.453,0.563,0.676,0.775,0.875,0.839,0.678,0.267,0....
DesignTime	(TimeStep_TM)/(0.85*Estimated Development Schedule')
Detected Code Errors	0
Code Error Detection Rate.in	'Code Error Detection Rate'
Code Rework Rate.out	'Code Rework Rate'

# Constants, Variables and Equations

Detected Design Errors	0
Design Error Detection Rate.in	'Design Error Detection Rate'
Design Rework Rate.out	'Design Rework Rate'
Errors Escaping Integration Test	0
Integration Test Error Escape Rate.in	'Integration Test Error Escape Rate'
Errors Fixed in Test_TEAM	'Errors Escaping Integration Test'
Errors Found in IT	0
Integration Test Errors Found Rate.in	'Integration Test Errors Found Rate'
Escaped Errors	0
Code Error Escape Rate.in	'Code Error Escape Rate'
Integration Test Error Escape Rate.out	'Integration Test Error Escape Rate'
Integration Test Errors Found Rate.out	'Integration Test Errors Found Rate'
Escaped Errors_TEAM	'Escaped Errors'
Estimated Development Schedule	$20 * 2.5 / \text{SCED Schedule Constraint\_EFM} * (\text{Calibrated COCOMO Constant\_EFM} * (0.06 * \text{Job Size\_EFM})^{1.2})^{0.32}$
Estimated Development Schedule_TEAM	'Estimated Development Schedule'
Estimated Test Schedule	$0.35 * 20 * 2.5 / \text{SCED Schedule Constraint\_EFM} * (\text{Test Effort Adjustment\_EFM} * \text{Calibrated COCOMO Constant\_EFM} * (0.06 * \text{Job Size\_EFM})^{1.2})^{0.32}$
Estimated Test Schedule_TEAM	'Estimated Test Schedule'
Final Defect Density	$\text{IF}(\text{Tasks Tested\_TEAM} > 1, \text{'Errors Fixed in Test\_TEAM'} / \text{Tasks Tested\_TEAM}, 0)$
Fraction Done	'Tasks Tested\_EFM' / 'Job Size\_EFM'
Fraction of Effort for Coding	0.2657
Fraction of Effort for Coding_TM	'Fraction of Effort for Coding'
Fraction of Effort for Design	0.454
Fraction of Effort for Design_TM	'Fraction of Effort for Design'
Fraction of Effort for Testing	0.255
Fraction of Effort for Testing_TM	'Fraction of Effort for Testing'
Fraction of Integration Tests that Find Errors	0.1
Fraction of Integration Tests that Find Errors_TM	'Fraction of Integration Tests that Find Errors'
Hiring and Manpower Allocation	$\text{PULSE}(((\text{SCED Schedule Constraint\_EFM}^2) * 1.46) * (20 * \text{Calibrated COCOMO Constant\_EFM} * (0.06 * \text{Job Size\_EFM})^{1.2}) / (20 * 2.5 * (\text{Calibrated COCOMO Constant\_EFM} * (0.06 * \text{Job Size\_EFM})^{1.2})^{0.32}), \text{STARTTIME}, 99999 * \text{TIMESTEP})$
Inspection Efficiency	0.6
Inspection Efficiency_ErrM	'Inspection Efficiency'

# Constants, Variables and Equations

◇	Inspection Effort per Task	0.19
◇	Inspection Effort per Task_EfM	'Inspection Effort per Task'
◇	Integration Test Efficiency	0.85
◇	Integration Test Efficiency_ErrM	'Integration Test Efficiency'
⊗	Integration Test Error Escape Rate	$\text{MIN}((1 - \text{Integration Test Efficiency\_ErrM}) * \text{IT Rate}, \text{'Escaped Errors'}/\text{TIMESTEP})$
⊗	Integration Test Error Fix Manpower Rate	'Integration Testing Error Detection Rate_EfM' * Testing Effort per Error_EfM'
⊗	Integration Test Errors Found Rate	$\text{MIN}(\text{Integration Test Efficiency\_ErrM} * \text{IT Rate}, \text{'Escaped Errors'}/\text{TIMESTEP})$
⊗	Integration Test Failing Rate	$\text{MIN}(\text{Fraction of Integration Tests that Find Errors\_TM} * \text{Integration Testing Rate}, \text{'Tasks Ready for Test'}/\text{TIMESTEP})$
⊗	Integration Test Passing Rate	$\text{MIN}((1 - \text{Fraction of Integration Tests that Find Errors\_TM}) * \text{Integration Testing Rate}, \text{'Tasks Ready for Test'}/\text{TIMESTEP})$
⊗	Integration Testing Error Detection Rate_EfM	'Integration Test Errors Found Rate'
⊗	Integration Testing Rate	$(\text{Testing Manpower Rate\_TM} * \text{Current Productivity\_TM}) / \text{Fraction of Effort for Testing\_TM} / \text{Testing Effort Adjustment\_TM}$
⊗	Integration Testing Rate_ErrM	'Integration Test Passing Rate'
⊗	IT Rate	$(\text{Defect Density\_ErrM} * \text{Integration Testing Rate\_ErrM}) / \text{Test Effort Adjustment\_ErrM}$
◇	Job Size	533.3
◇	Job Size_EfM	'Job Size'
◇	Job Size_TEAM	'Job Size'
⊗	Job Size_TM	'Job Size'
⊗	Learning Curve	$\text{GRAPHCURVE}(\text{Fraction Done}, 0, 1.0, \{100.0, 100.0, 100.0, 100.0, 100.0, 100.0, 100.0, 100.0, 100.0, 100.0, 100.0, 100.0, 100.0\})$
⊗	Madachy DesignCode Calibration	'Madachy DesignCode Dx_Dataspread' / Powersims Dx DataSpread for DesignCode Staff Curve'
⊗	Madachy DesignCode Calibration_EfM	'Madachy DesignCode Calibration'
◇	Madachy DesignCode Dx_Dataspread	0.05882100000000
⊗	Madachy Test Calibration	'Madachy Test Dx_Dataspread' / Powersims Dx DataSpread for Test Staff Curve'
⊗	Madachy Test Calibration_EfM	'Madachy Test Calibration'
◇	Madachy Test Dx_Dataspread	0.14286450
□	Manpower Pool	0
↔	Attrition Rate.out	'Attrition Rate'
↔	Hiring and Manpower Allocation.in	'Hiring and Manpower Allocation'
⊗	Max Productivity	$\text{'Job Size\_EfM'} / (20 * \text{Calibrated COCOMO Constant\_EfM} * (0.06 * \text{Job Size\_EfM})^{1.2})$
⊗	Non-Unit Testing Rate	$(1 - \text{Unit Test Practice\_TM}) * \text{Coding Rate}'$


















# Constants, Variables and Equations

● Powersims Dx DataSpread for DesignCode Staff...	$17 * \Delta_{Time}$
● Powersims Dx DataSpread for Test Staff Curve	$7 * \Delta_{Time}$
● Re-worked Code Error Generation Rate	$IF('Errors Found in IT' > 0, 'Code Error Density\_ErrM' * Task Re-coding Rate\_ErrM', 0) / \Delta_{Time}$
■ Requirements	0
⚡ Design Rate.out	'Design Rate'
➡ Requirements Generation Rate.in	'Requirements Generation Rate'
● Requirements Generation Rate	$PULSE('Job Size\_TM', STARTTIME, 9999 * \Delta_{Time})$
◇ Resource Leveling	0
◇ Resource Leveling\_Efm	'Resource Leveling'
■ Reworked Code Errors	0
➡ Code Rework Rate.in	'Code Rework Rate'
■ Reworked Design Errors	0
➡ Design Rework Rate.in	'Design Rework Rate'
● Runmax Defect Density	$RUNMAX('Running Defect Density')$
● Running Defect Density	$IF('Tasks Ready For Test\_TEAM' > 1, 'Escaped Errors\_TEAM' / 'Tasks Ready For Test\_TEAM', 0)$
■ Sampled Defect Density	0
➡ Sampler.in	Sampler
● Sampler	$PULSE('Running Defect Density', STARTTIME + \Delta_{Time} * (0.65 * 'Estimated Development Schedule\_TEAM' - 1), 9999 * \Delta_{Time})$
◇ SCED Schedule Constraint	1
◇ SCED Schedule Constraint\_Efm	'SCED Schedule Constraint'
● Task Re-coding Rate	$MIN('Test Error Fix Manpower Rate\_TM' * 'Current Productivity\_TM' / 'Fraction of Effort for Testing\_TM', 'Tasks Failing' / \Delta_{Time})$
● Task Re-coding Rate\_ErrM	'Task Re-coding Rate'
■ Tasks Coded	0
➡ Coding Rate.in	'Coding Rate'
⚡ Non-Unit Testing Rate.out	'Non-Unit Testing Rate'
➡ Task Re-coding Rate.in	'Task Re-coding Rate'
⚡ Unit Testing Rate.out	'Unit Testing Rate'
■ Tasks Designed	0
⚡ Design Inspection Rate.out	'Design Inspection Rate'
⚡ Design Non-Inspection Rate.out	'Design Non-Inspection Rate'
➡ Design Rate.in	'Design Rate'
■ Tasks Failing	0
➡ Integration Test Failing Rate.in	'Integration Test Failing Rate'
⚡ Task Re-coding Rate.out	'Task Re-coding Rate'

# Constants, Variables and Equations

Tasks for Coding	0
Coding Rate.out	'Coding Rate'
Design Inspection Rate.in	'Design Inspection Rate'
Design Non-Inspection Rate.in	'Design Non-Inspection Rate'
Tasks Ready for Test	0
Code Inspection Rate.in	'Code Inspection Rate'
Code Non-Inspection Rate.in	'Code Non-Inspection Rate'
Integration Test Failing Rate.out	'Integration Test Failing Rate'
Integration Test Passing Rate.out	'Integration Test Passing Rate'
Tasks Ready For Test_TEAM	'Tasks Ready for Test'
Tasks Tested	0
Integration Test Passing Rate.in	'Integration Test Passing Rate'
Tasks Tested_EfM	'Tasks Tested'
Tasks Tested_TEAM	'Tasks Tested'
Tasks Unit Tested	0
Code Inspection Rate.out	'Code Inspection Rate'
Code Non-Inspection Rate.out	'Code Non-Inspection Rate'
Non-Unit Testing Rate.in	'Non-Unit Testing Rate'
Unit Testing Rate.in	'Unit Testing Rate'
Test Effort Adjustment	$(0.0803*(20*Calibrated\ COCOMO\ Constant\_TEAM*(0.06*Job\ Size\_TEAM)^{1.2})+Job\ Size\_TEAM*Sampled\ Defect\ Density*Testing\ Effort\ per\ Error\_TEAM)/(0.0803*(20*Calibrated\ COCOMO\ Constant\_TEAM*(0.06*Job\ Size\_TEAM)^{1.2})+Job\ Size\_TEAM*3*Testing\ Effort\ per\ Error\_TEAM)$
Test Effort Adjustment_EfM	'Test Effort Adjustment'
Test Effort Adjustment_ErrM	'Test Effort Adjustment'
Test Error Fix Manpower Rate_TM	'Integration Test Error Fix Manpower Rate'
Test Schedule Adjustment	'Estimated Test Schedule_TEAM'/(0.35*Estimated Development Schedule_TEAM)
Test Staff Curve	GRAPH(TestingTime,0,7*DeltaTime_TM*Madachy Test Calibration_EfM',{0,0,0.127,0.424,0.781,0.85,0.75,0.6,0,0})
Testing Effort Adjustment_TM	'Test Effort Adjustment'
Testing Effort per Error	$0.16*Calibrated\ COCOMO\ Constant'$
Testing Effort per Error_EfM	'Testing Effort per Error'
Testing Effort per Error_TEAM	'Testing Effort per Error_EfM'
Testing Manpower Level Adjustment	'Test Effort Adjustment'/Test Schedule Adjustment'
Testing Manpower Level Adjustment_EfM	'Testing Manpower Level Adjustment'
Testing Manpower Rate	'Manpower Pool'*Test Staff Curve'*Testing Manpower Level Adjustment_EfM'/TIMESTEP
Testing Manpower Rate_TE	'Testing Manpower Rate'

# Constants, Variables and Equations

 Testing Manpower Rate_TM	'Testing Manpower Rate'
 TestingTime	$(\text{TimeStep\_TM} - 0.65 * \text{Estimated Development Schedule}) / \text{Estimated Test Schedule}$
 TimeStep_number	TIMESTEP
 TimeStep_TM	TimeStepNumber
 TimeStepFraction	$(\text{TIME} - \text{STARTTIME}) / (\text{STOPTIME} - \text{STARTTIME})$
 TimeStepNumber	$(\text{TIME} - \text{STARTTIME}) / (\text{TIMESTEP})$
 Total Manpower Rate	'Code Inspection Manpower Rate_TE' + 'Code Rework Manpower Rate_TE' + 'Coding Manpower Rate_TE' + 'Design Inspection Manpower Rate_TE' + 'Design Manpower Rate_TE' + 'Design Rework Manpower Rate_TE' + 'Testing Manpower Rate_TE'
 Undetected Design Errors	0
 Design Error Escape Rate.in	'Design Error Escape Rate'
 Unit Test Delay Time	10 <<da>>
 Unit Test Delay Time_TM	'Unit Test Delay Time'
 Unit Test Efficiency	0.75
 Unit Test Efficiency_ErrM	'Unit Test Efficiency'
 Unit Test Practice	1
 Unit Test Practice_TM	'Unit Test Practice'
 Unit Testing Rate	$\text{DELAYPPL}(\text{Unit Test Practice\_TM} * \text{Coding Rate}, \text{Unit Test Delay Time\_TM})$
 Unit Testing Rate_ErrM	'Unit Testing Rate'