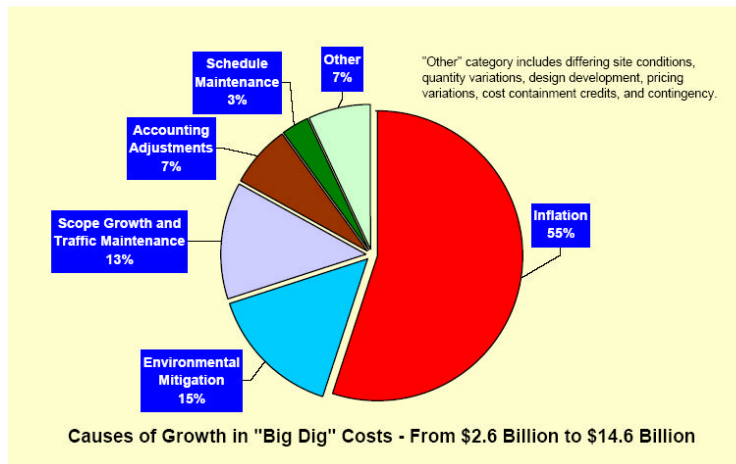

Cost Engineering in Axiomatic Design

2.882

May 2nd, 2005

Cost: What's the problem?

- “Cost nightmare”
 - The Big Dig
 - \$2.6B (1982) to \$14.6B (2004)



Boston's Big Dig

Photo removed for copyright reasons.

- Ingalls Shipbuilding Co.
 - Continuous design change, required by the Navy
 - \$2.7B unsettled claim

USS Peleliu

Photo removed for copyright reasons.

Freiman Curve

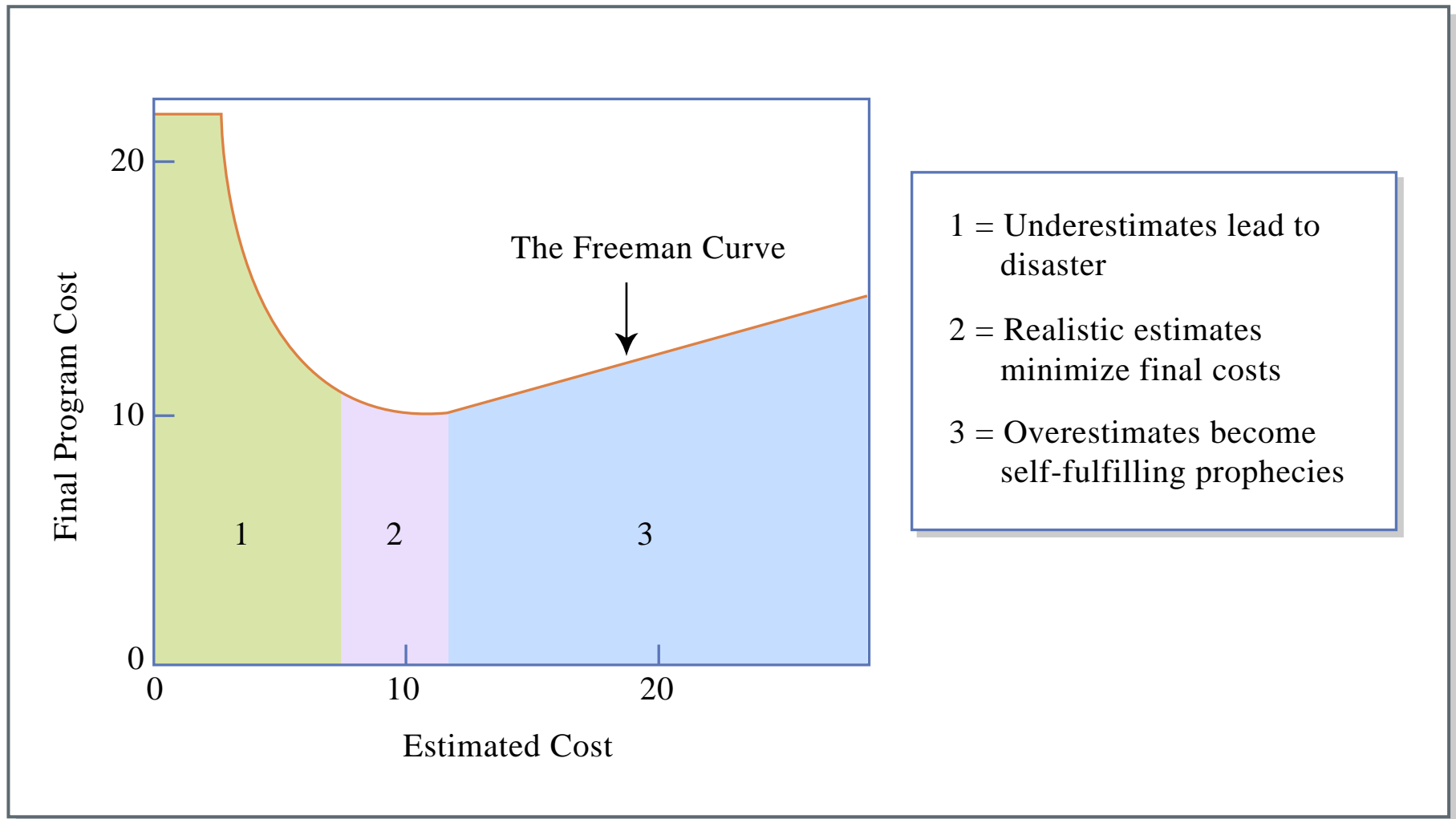


Figure by MIT OCW. Adapted from Freiman, F. R. "The Fast Cost Estimating Models." *AACE Transactions* (1983).

-
- Fail to address:
 - Credible cost estimation
 - Cost drivers
 - Cost management
 - Schedule risk

WHY does a system
cost how much?

- We need ...
 - Systematic approach
 - Better utilization of cost data

TRACEABILITY

Goals & Approaches

- Goals
 - Enhance the credibility of life cycle cost estimation
 - Quickly predict the cost impact of engineering changes to the system
 - Identify key cost drivers to guide the cost reduction effort
- Approaches
 - Develop a general method for integrating cost information into the system architecture
 - Development, Production, Operation phase
 - Develop a method to predict the cost of system changes
 - Requirement changes, Solutions changes
 - Integrate the method into a usable tool for designers/engineers

Value

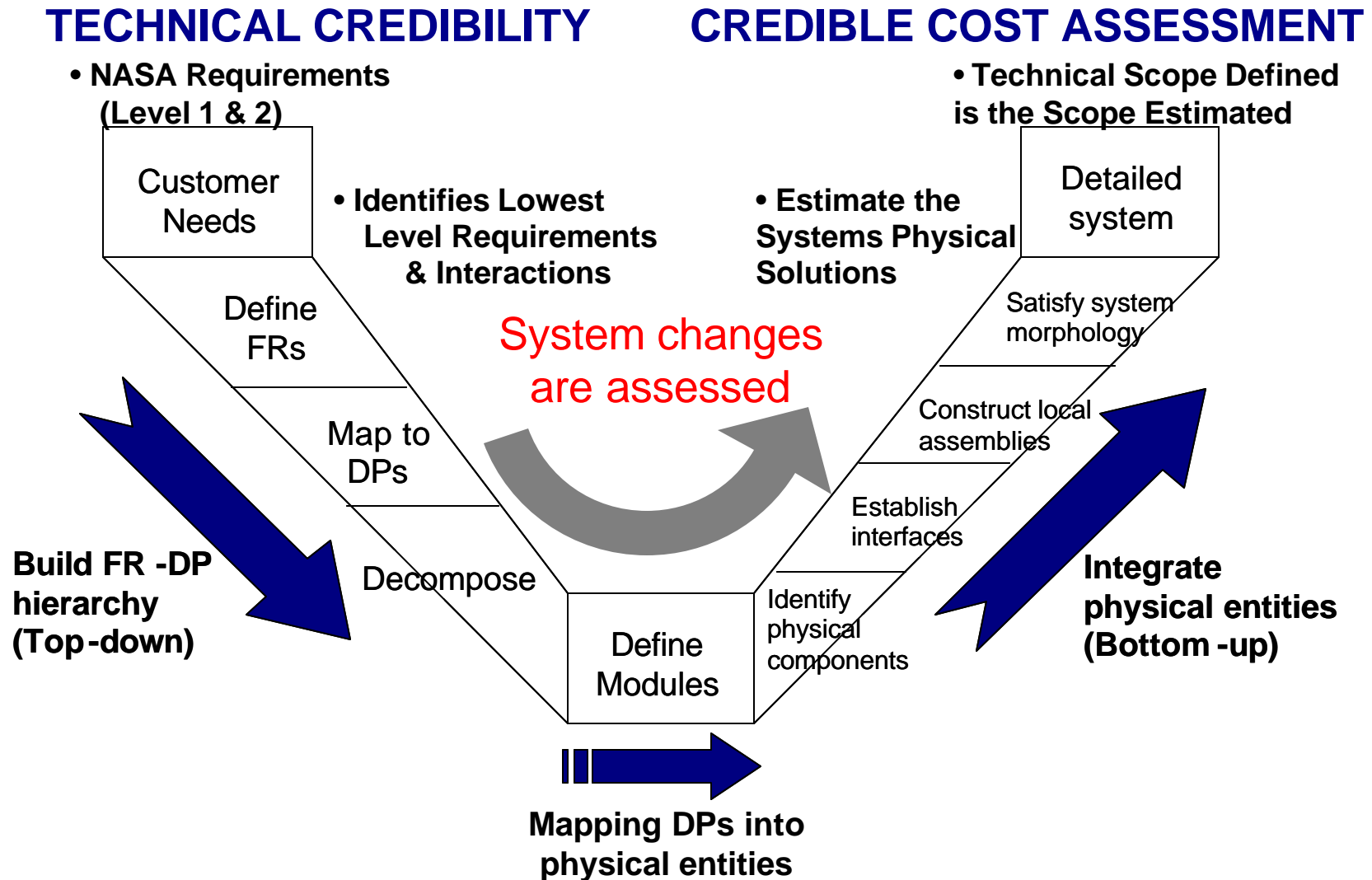
- Cost Credibility

- Cost information is tied to system design information via Axiomatic Design (AD) framework
- **Completeness, Visibility**
- Unified framework for cost estimation at different stages of system design by constructing a hierarchical structure

- Capability to Assess the Cost Impact of Changes

- Ramification of changes in a requirement and/or design solution is captured by AD framework
- **Traceability**
- The estimate of cost impact is quickly generated to support decision making process
- Key cost drivers can be identified

System Design & Development



Software Tool to Aid the Process

Acclaro Designer - [C:\Users\stlee\LM_cost_ADSIRCS_chipdemo1.ad3]

Cost Analysis

Symmetric Tree Cost

Cost Map Summary DP Costs CU Costs Detailed Output

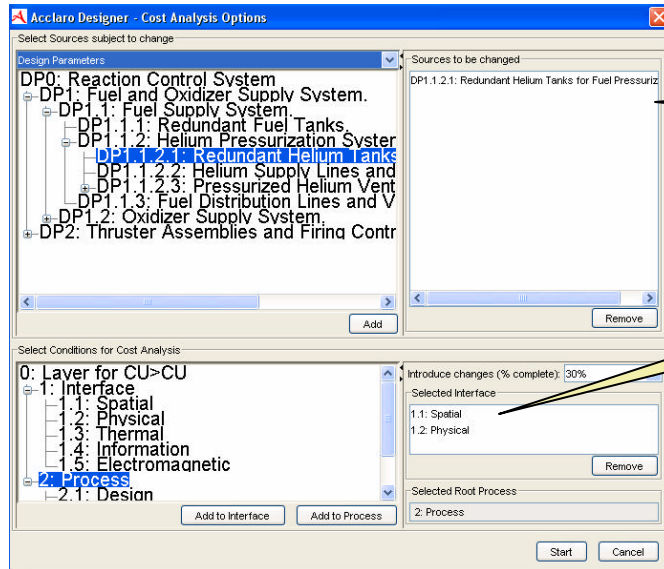
#	Functional Requirements	Design Parameters	Baseline Development Cost (K)
0	FR Accelerate the vehicle to control attitude	DP Reaction Control System	\$ 217,552
1	FR Produce required total thrust.	DP Fuel and Oxidizer Supply System.	\$ 71,176
1.1	FR Provide Fuel.	DP Fuel Supply System.	\$ 34,994
1.1.1	FR Store fuel	DP Redundant Fuel Tanks.	\$ 16,791
1.1.2	FR Pressurize fuel tanks.	DP Helium Pressurization System.	\$ 11,924
1.1.2.1	FR Store Helium.	DP Redundant Helium Tanks for Fuel	\$ 7,142
1.1.2.2	FR Supply Helium to fuel tanks.	DP Helium Supply Lines and Valving Manifolds.	\$ 1,147
1.1.2.3	FR Prevent overpressurization of fuel tanks.	DP Pressurized Helium Vent System.	\$ 3,634
1.1.2.3.1	FR Route excess helium to purge.	DP Helium Vent Lines.	\$ 490
1.1.2.3.2	FR Control amount of helium vented.	DP Triple Redundant Helium Vent Valves.	\$ 3,143
1.1.3	FR Distribute fuel.	DP Fuel Distribution Lines and Valving Manifolds.	\$ 6,277
1.2	FR Provide Oxidizer.	DP Oxidizer Supply System.	\$ 36,182
1.2.1	FR Store oxidizer.	DP Redundant Oxidizer Tanks.	\$ 18,863
1.2.2	FR Pressurize oxidizer tanks.	DP Helium Pressurization System.	\$ 11,741
1.2.2.1	FR Store Helium.	DP Redundant Helium Tanks for Oxidizer	\$ 7,009
1.2.2.2	FR Supply Helium to oxidizer tanks.	DP Helium Supply Lines and Valving Manifolds.	\$ 1,277
1.2.2.3	FR Prevent overpressurization of oxidizer	DP Pressurized Helium Vent Lines.	\$ 3,454
1.2.2.3.1	FR Route excess helium to purge.	DP Helium Vent Lines.	\$ 400
1.2.2.3.2	FR Control amount of helium vented.	DP Triple Redundant Helium Vent Valves.	\$ 3,053
1.2.3	FR Distribute oxidizer.	DP Oxidizer Distribution Lines and Valving	\$ 5,577
2	FR Control thrust firing / direction.	DP Thruster Assemblies and Firing Control System.	\$ 146,376
2.1	FR Control forward thrust.	DP Aft Facing Thruster Group.	\$ 48,792
2.1.1	FR Supply fuel to Aft Facing Thruster Groups.	DP Fuel Supply Lines.	\$ 1,091
2.1.2	FR Filter fuel.	DP Fuel Line Filter.	\$ 389

Run Simulation Report Simulation

Courtesy of Axiomatic Design Solutions, Inc. Used with permission.

Software Tool Demonstration

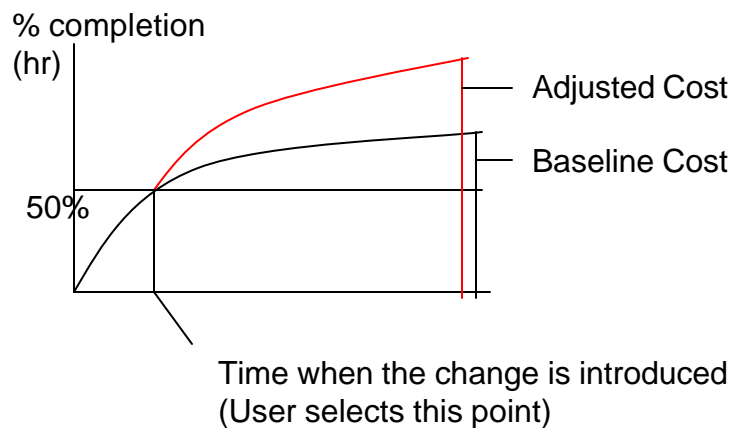
SDCM Development Module



DP1.3.1 is Evaluated for Change

Nature of a 'change' is further specified

Simulation input (change, project phase), Result (cost impact), and Details are summarized



Cost Model Output Report

Assumptions

Change Source	DP1.1.2.1: Redundant Helium Tanks for Fuel Pressurization.
Interface Change	1.1: Spatial 1.2: Physical
Percent Complete	30%

Output

Number of Products Affected (DPs) : 13

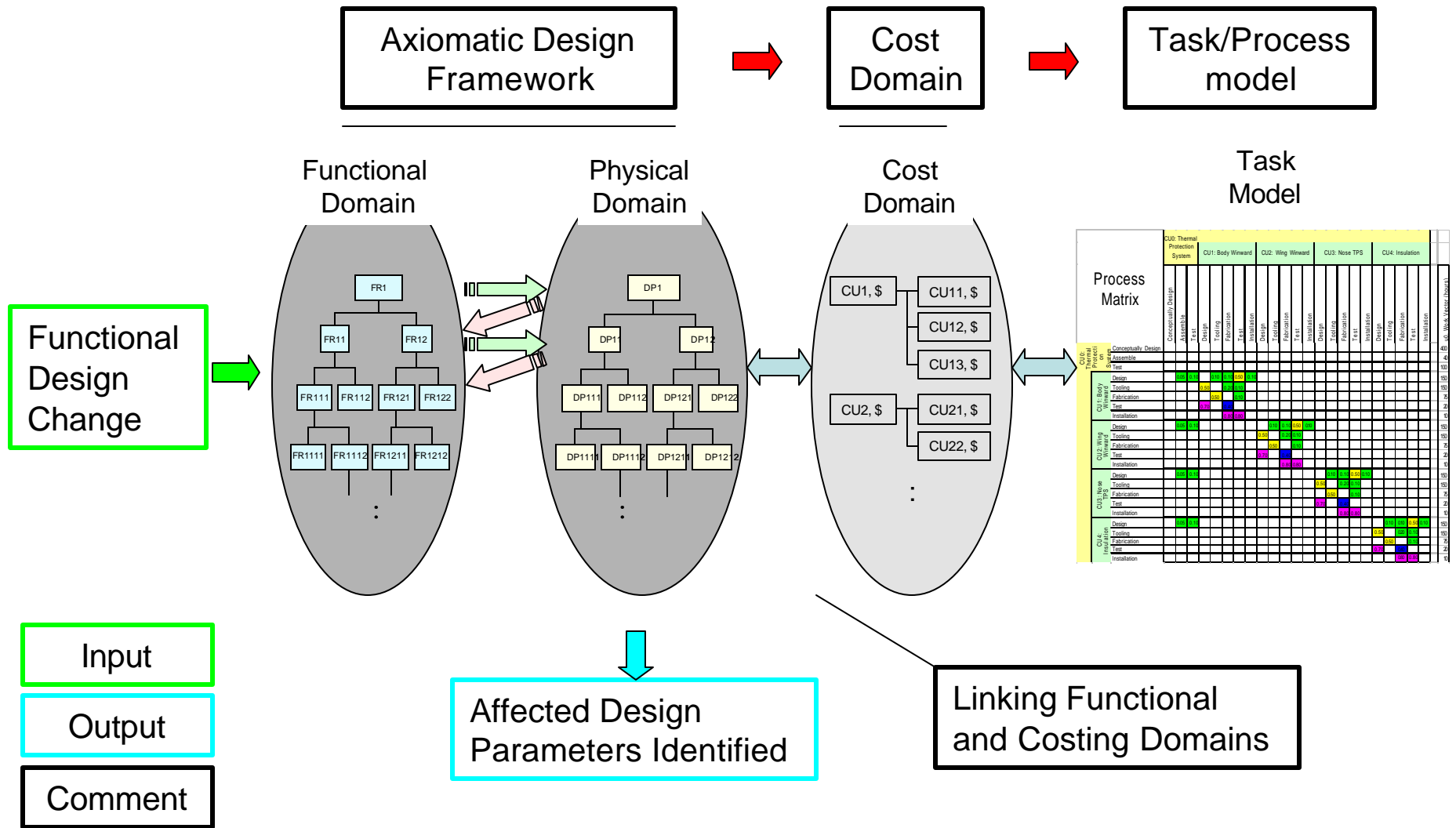
Cost Impact

	Baseline Cost	Adjusted Cost	Delta Cost
Development	\$217,552K	\$240,897K	\$23,344K
Production			
Operation			

Directly Affected Products (DPs)

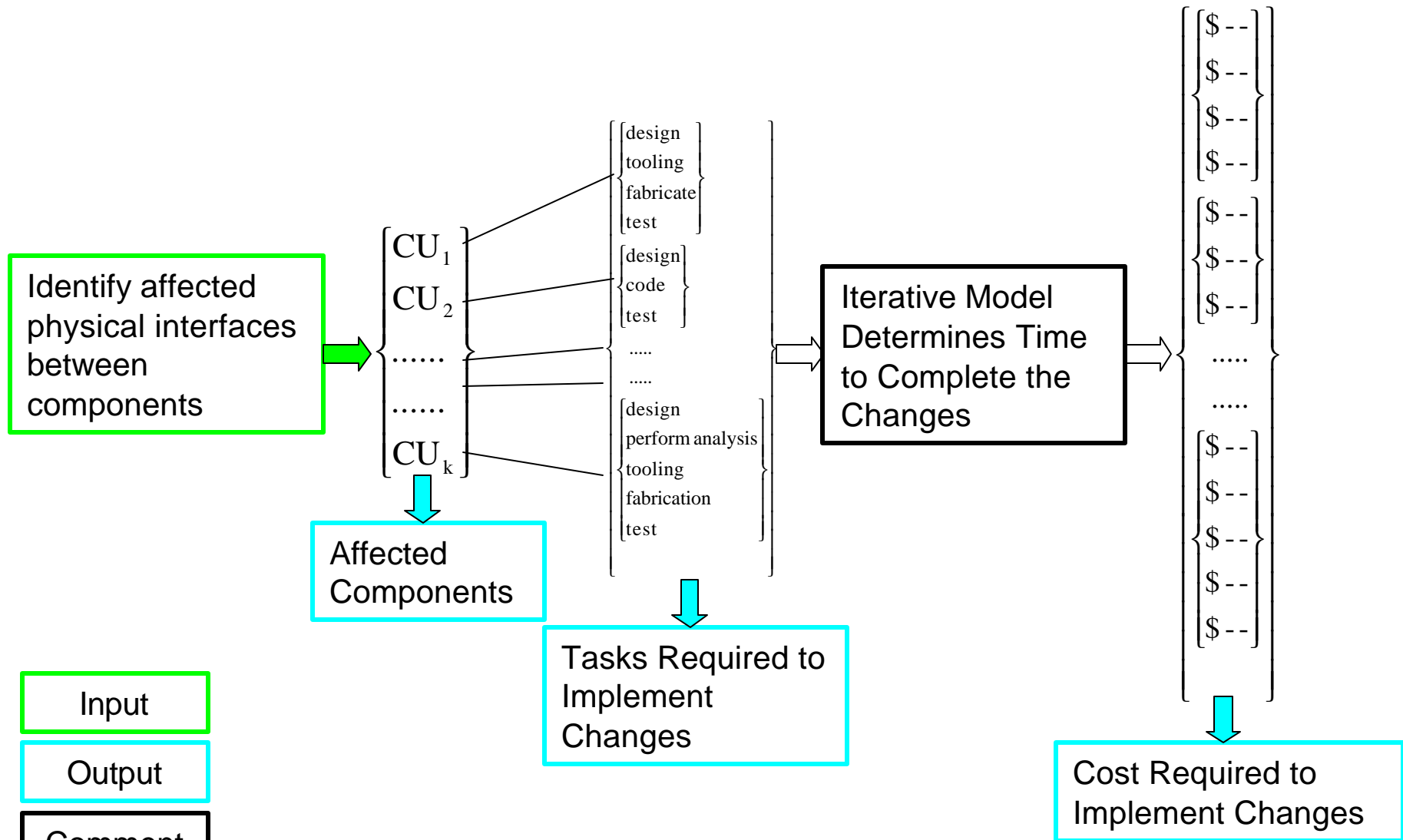
- DP1.1.2.1: Redundant Helium Tanks for Fuel Pressurization.
- DP1.1.2.2: Helium Supply Lines and Valving Manifolds.
- DP1.1.2.3.2: Triple Redundant Helium Vent Valves.
- DP1.1.3: Fuel Distribution Lines and Valving Manifolds.
- DP2.1.1: Fuel Supply Lines.
- DP2.2.1: Fuel Supply Lines.
- DP2.3.1: Fuel Supply Lines.
- DP2.1.3: Fuel Control Valve.

Development Module Model Structure



- Input**
- Output**
- Comment**

Development Module Model Structure



Input
Output
Comment

Iteration model

	Task A	Task B
Task A		0.5
Task B	0.3	

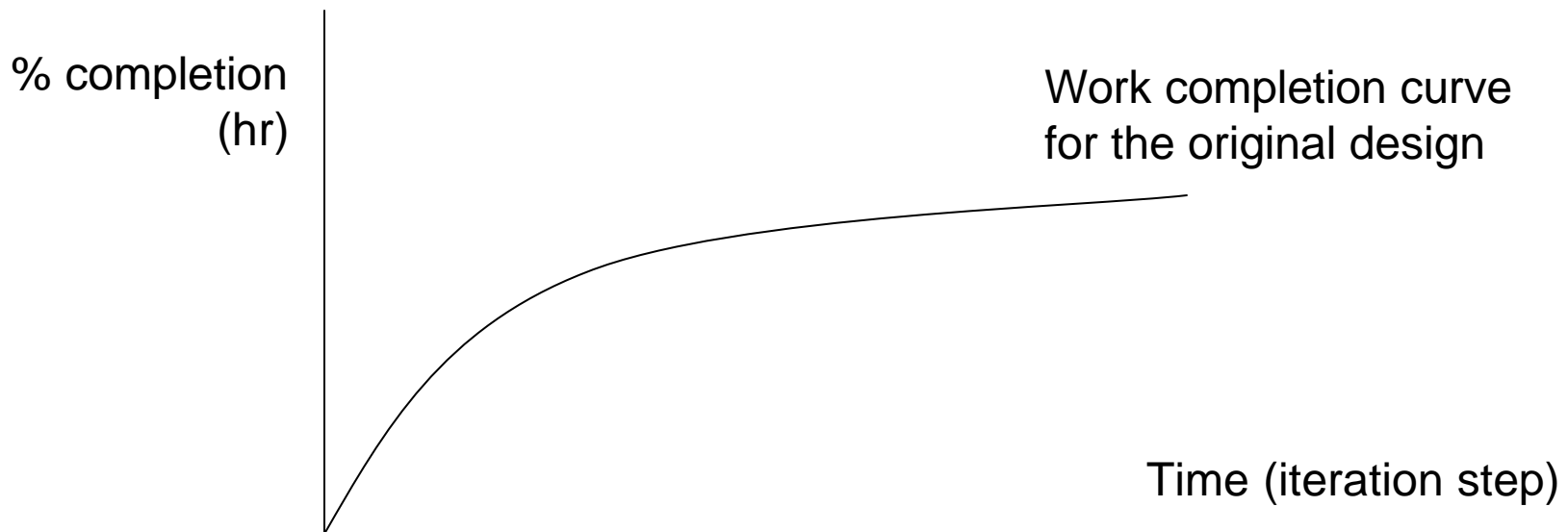
Work Transformation Matrix

$$u_n = WT \cdot u_{n-1}$$

$$U = u_0 + u_1 + \dots + u_N$$

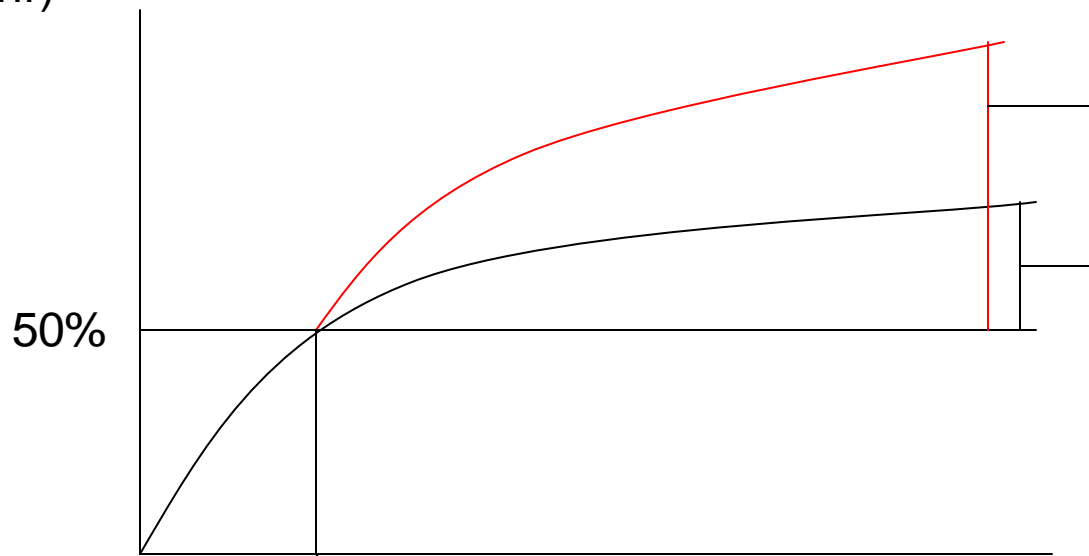
$$= u_0 + WT \cdot u_0 + WT \cdot (WT \cdot u_0) \dots$$

$$= (1 + WT + WT^2 + \dots + WT^N) \cdot u_0$$



Cost Impact of Change

% completion
(hr)



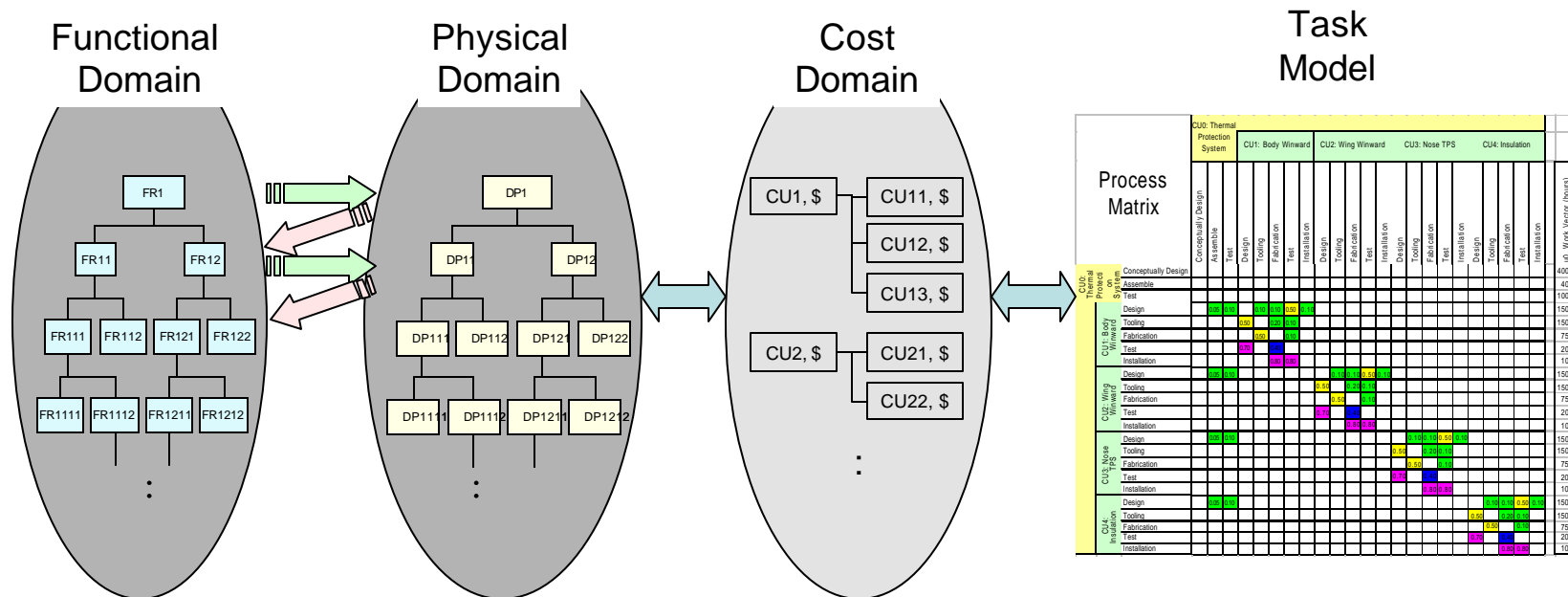
Cost penalty = $Y - X$

Remaining work for
original design, X

User selects this point

Summary

Complete Traceability from Design to Cost Information



Steps

1. Identify affected DP's from FR change
2. Identify CU' corresponding to DP's
3. Identify CU'' from CU'
4. Estimate % rework input
5. Estimate total change-workload