Process-Based Cost Modeling

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Background

- Cost analysts have used weight-based parametric cost models for 50 years*
- Weight-based estimates have advantages, but also limitations
- Recent focus has been placed on developing next-generation cost models**

*Joe Hamaker, "But What Will It Cost? The Evolution of NASA Cost Estimating" , Issues in NASA Program and Project Management, 1991.

**Andy Prince, "Weight and the Future of Space Flight Hardware Cost Modeling,", SCEA National Conference, 2003

Next Generation Cost Modeling

- Traditional parametric approaches are very useful for cost estimating
- But even the most sophisticated multivariate models have limitations
  - One example is out-of-date samples and small sample sizes for some manned launched vehicle subsystems
    - Crew Accommodations
    - Crew Life Support
- There is need for a tool to supplement existing parametric models

Overview

- The objective is to improve state-of-the-art cost modeling techniques using process-based estimation
- Process-based models supplement traditional parametric tools
  - they are ***not*** intended to replace parametric estimates
- Traditional parametrics provide an early estimate of a project's cost
- These traditional weight-based statistical estimates can be greatly refined using a process-based model

Process-Based Modeling

- Process-based cost modeling promises to provide a greater level of fidelity for cost estimating
  - May be especially useful for large projects
- Parametric analysis has tended to focus on the "what" of cost
- Process-based modeling focuses on the "how"
- Process-based modeling is a relatively new approach to cost estimation
  - Process-based models are also being developed by Boeing and Galorath

Process-Based Modeling (cont.)

- Process-based modeling provides cost estimates by relating cost drivers to the processes that occur during design, development, test, evaluation, and production

- Cost drivers affect cost by directly impacting the cost of the processes
  - Adding/removing some process,
  - Changing the number of times some process occurs
  - Changing the cost of a specific process

- In addition to serving as an estimation tool, the process-based model will also be a communication tool between cost analysts and project personnel and management

Scope

- Capture all processes that occur during Phase C/D, from ATP up to Operational Readiness Review
- Focus on manned launch vehicles only
- Reflect recent aerospace program development and experience
- Model is top-down, with processes defined at an intermediate level (rather than the lowest level possible)

Outline of the Modeling Process

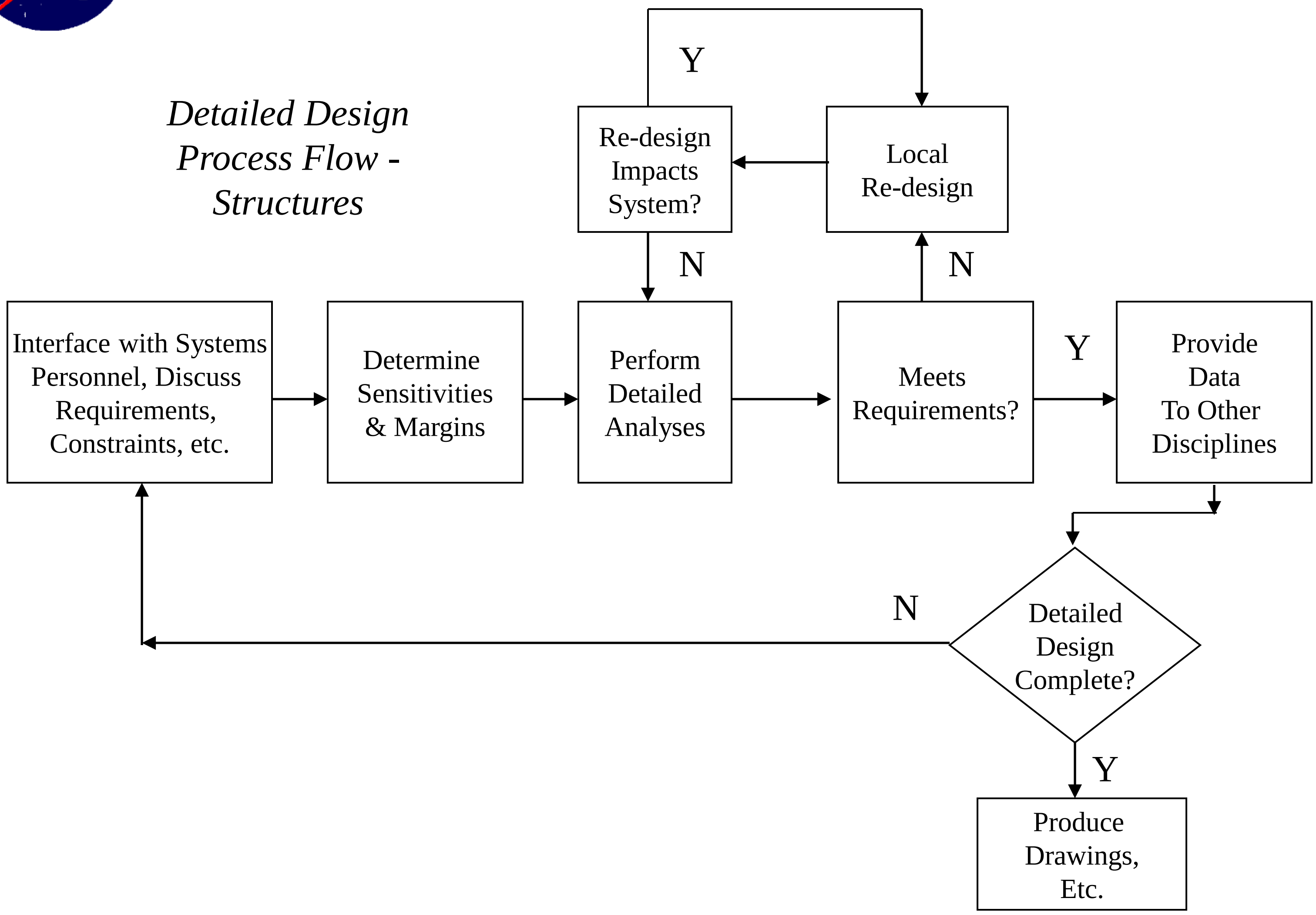
- Document processes at the subsystem level – design, tooling, fabrication, assembly, etc., and account for interfaces
- Collect detailed time-phased costs for several programs
- Analyze historical data
- Create calibrated models
- Develop algorithms for relating complexity generators to cost

Cataloging Processes

- Created detailed process flows (process catalogue) for all spacecraft-related subsystems
  - Includes hardware and systems engineering/integration subsystems
- Met with subject-matter experts for each subsystem to validate the process flows and revise as needed
- Catalogued over 500 generic processes

Process Catalog - Example

Detailed Design Process Flow - Structures



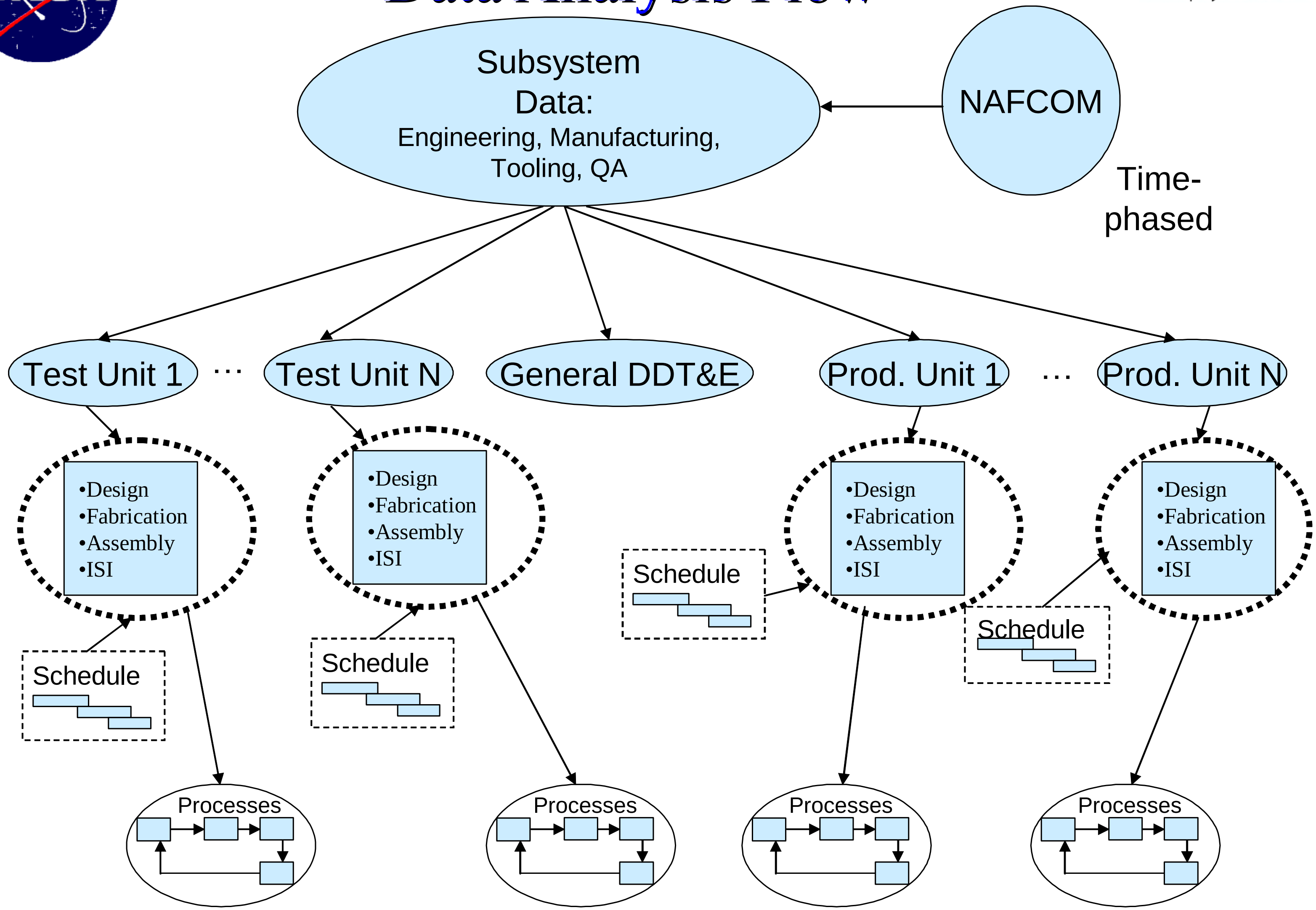
Data Collection

- Collected detailed cost data for several missions
  - Apollo
  - Cassini
  - Chandra
  - Shuttle
  - Galileo
- In the process of collecting data for other missions
  - Gemini
  - X-37

Data Analysis

- Collected detailed, time-phased WBS level cost and data for Shuttle and Apollo
- Allocated cost to the individual process level using schedules and other information

Data Analysis Flow



Model Development - Shuttle

- Analyzed detailed, time-phased historical data for Shuttle Orbiter and modeled 22 subsystems and over 700 processes

Structures – 58	Technical Mgt. and Support – 24
Thermal Protection – 43	Provisioning – 9
EPD&C – 40	Trainers and Mockups – 31
GN&C – 38	Mechanical Systems – 38
CC&DH – 59	Auxiliary Propulsion – 48
Avionics Dev. And Int. Labs – 19	ECLS – 31
Approach and Landing Tests – 23	IACO – 24
Crew Station – 33	GSE – 37
Major Test and Support – 36	Power Generation (APU) – 35
Flight Tech. Analysis – 11	System Requirements – 11
Design and Project Control – 19	Safety and Reliability - 24

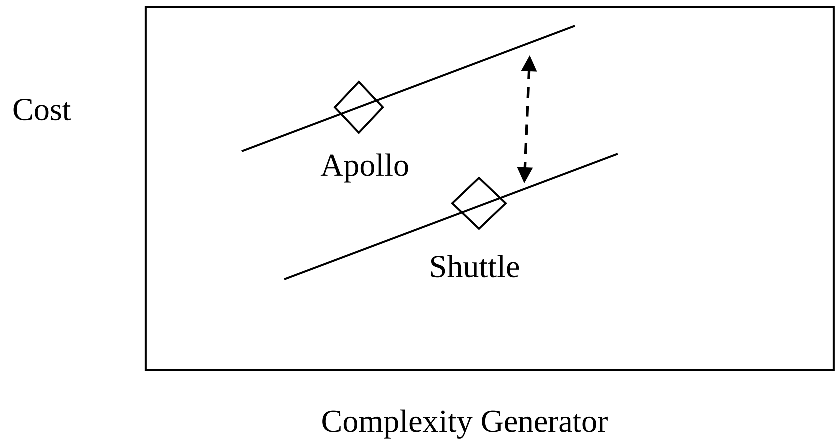
Model Development - Apollo

- Analyzed detailed, time-phased historical data for Apollo CSM and modeled 8 subsystems and over 250 processes

Crew Module Structures – 39	Service Module Structures – 38
Crew Module Heat Shield - 37	Crew Accommodations - 33
Crew Module Mechanisms - 37	Launch Escape Structures - 38
Earth Landing System - 37	Launch Escape SRMs - 38

Calibrated Models

- Calibrating the models to specific historical programs is similar in its approach to using analogy-calibrated weight based CERs



- Our efforts to date have been focused on calculating the “intercepts”
- We have more “intercepts” to calculate, but we must also must calculate the “slope”

Algorithms and Process Drivers

- NAFCOM complexity generator inputs are used
- Also, based on our research to date and the information gathered from subject matter experts and several key process drivers will be added, including
  - Material type
  - Hardware geometry
  - Organizational structure

Process-Based Modeling and NAFCOM

- Process-based model is at the subsystem level
  - Structures
  - Thermal Control
  - Systems Engineering
  - Etc.
- Cost drivers include all the NAFCOM complexity generators, plus others:
  - Material Type
  - Organization Structure
  - Etc.

Example – Detailed Structural Design Cost Drivers

- NAFCOM Cost Drivers for Structures Include:
  - Weight
  - New Design
  - Engineering Management
  - Manufacturing Methods
  - Number of Deployed Structures
  - Funding Availability
  - Test Approach
  - Integration Complexity
  - Amount of Pre-Development Study
  - Large Inert Structure (Yes/No)

Example – Relating % New Design and Engineering Management To Cost

- Engineering Management reflects the experience of the design team and the environment of the design effort
- Both % New Design and Engineering Management can range from 0 to 100
- Detailed Structural Design has three sets of loops
- One of the projects (but not the only project) to which the model is calibrated is Shuttle - for Shuttle, the number of iterations was 5, 3, and 2

Example – Relating % New Design and Engineering Management To Cost (cont'd)

- Engineering Management
  - 0-12, Minimum Design Changes
  - 13-37, Few Design Changes
  - 38-62, Moderate Design Changes
  - 63-87, Dedicated Design Team, Experiences Sig. Reqmts. Changes
  - 88-100, Distributed Design Team, Dependent Upon Major Technological Advances
- % New Design
  - 0-10, Reflight
  - 11-21, Minor Mods., No Requal.
  - 22-31, Minor Mods., Requal.
  - 32-55, Moderate Mods.
  - 56-73, Significant Mods.
  - 74-85, Based on Prev. Design
  - 86-96, Similar to Prev. Design
  - 97-100, New Design

Example – Relating % New Design and Engineering Management To Cost (cont'd)

- Using the Shuttle values as a point of departure as an example, the definitions of levels of engineering management and % new design, we have the following table:

% New Design

		0-10	11-21	22-31	32-44	45-55	56-63	64-73	74-85	86-96	97-100
	0-12	1,0,0	1,0,0	1,0,0	2,0,0	2,0,0	3,0,0	3,0,0	4,0,0	5,0,0	5,0,0
	13-37	1,1,0	1,1,0	1,1,0	2,1,0	2,1,0	3,1,0	3,1,0	4,1,0	5,1,0	5,1,0
Eng. Mgt.	38-62	1,2,1	1,2,1	1,2,1	2,2,1	2,2,1	3,2,1	3,2,1	4,2,1	5,2,1	5,2,1
	63-87	1,3,1	1,3,1	1,3,1	2,3,1	2,3,1	3,3,1	3,3,1	4,3,1	5,3,1	5,3,1
	88-100	1,3,2	1,3,2	1,3,2	2,3,2	2,3,2	3,3,2	3,3,2	4,3,2	5,3,2	5,3,2

Additional Products

In addition to providing a modeling tool, an additional product of the process-based model is the most complete and detailed time-phased breakout of Shuttle and Apollo costs known to exist

Future Plans

- Incorporate recent advances in aerospace design and manufacturing
- Make model applicable to generic launch vehicles
- Test the model and compare results to NAFCOM
- Deliver a stand-alone Excel-based prototype model in November for use in the evaluation of future launch vehicle architectures
- Eventually incorporate model into NAFCOM