

Integrating Cost into Model-Based Engineering Environments

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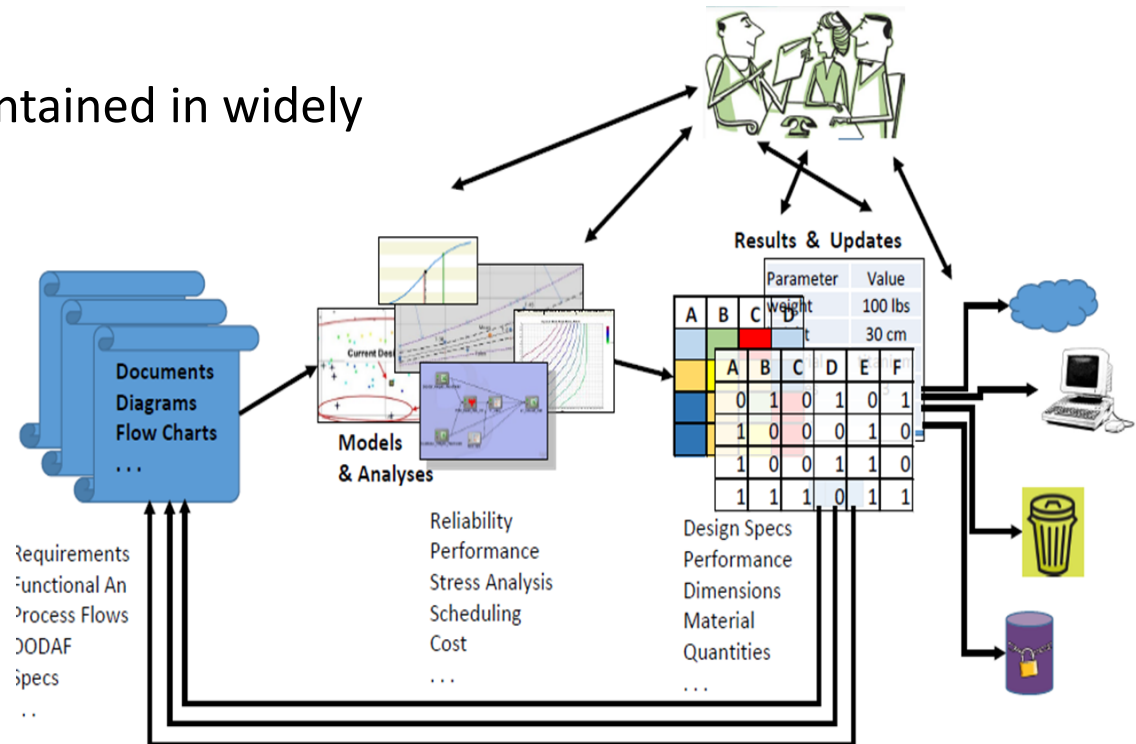
Abstract

- Model-based Engineering (MBE) incorporates digital models to represent system-level physical attributes and operational behavior throughout the system life-cycle.
- To date, many MBE efforts have focused on technical requirements with little emphasis on cost.
- Integrating cost models into MBE enables rapid exploration of design trades and associated cost impacts, traceability between requirements, cost targets and early identification of affordability issues.
- Here, we present the latest results from several ongoing efforts as a continuation of our 2019 presentation.

Historical Engineering Process

Document based actions:

- some model-based
- some connectivity
- artifacts (data) are maintained in widely dispersed locations
- cost is typically siloed



Activities are sequential and siloed. Cost is often a tertiary consideration.

Current Evolution

Recent improvements in managing lifecycle change of products

- “Digital Thread” Integrated MBE
 - Engineering Design and Analysis
 - Driven by a multitude of factors:
 - Safety
 - Improvement (Quality)
 - Cost

Cost

- Cost is often NOT addressed concurrently in the change cycle
 - It’s often a tertiary element AFTER the change is designed

Challenge:

- Make cost an element EARLY in the design phase and concurrent with other change activity

Make Cost Data Available EARLY to Decision Makers

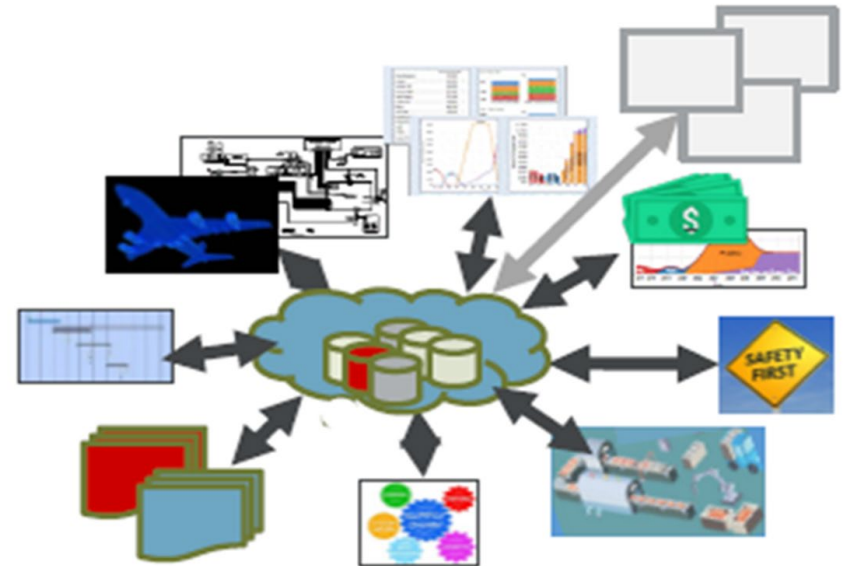
Integrated Model Based Engineering

Integrated MBE

- Central source of “Truth”
- Information is updated and made available in “real time”

MBE Data

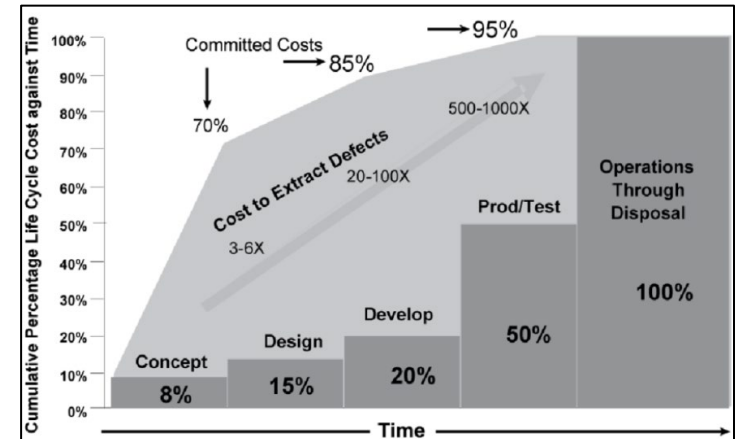
- Design parameters
(ex. CAD Data, FEA, CFD)
- Logical/functional models
- Requirements (Specifications)
- Requirement verifications
(Documentation)
- Notifications of changes
- Production Planning
- Cost ? Dated ☹️



Activities are concurrent and results shared among stakeholders

Product Change

- Building on our previous work of integrating cost analysis for **production engineering***, our current effort looked to expand the use of cost analysis at the **product change** level, integrated into an MBE environment.
- PLM and change control elements used within the MBE environment are the means to communicate requested or required changes.
- Identifying the cost impact of the proposed change provides valuable insight into the viability of the change.
- Better to address change EARLY in life cycle rather than LATER due to increase in cost (as shown here).



Reference: INCOSE System Engineering Handbook v4

*presented at 2019 ICEAA Annual Workshop

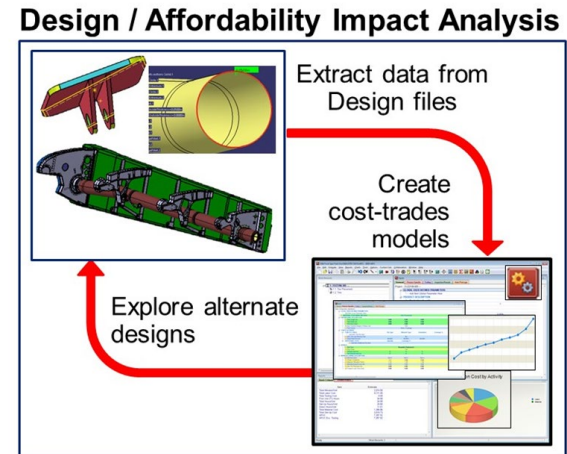
Change is expensive, recognize the cost early

Current Effort

For this effort, we analyzed the cost impacts of changes to a major structural assembly of an airplane

In order to connect cost modeling tools to PLM tools, we first identified a variety of metrics that drive cost into the assembly

- Materials of construction
- Tolerances of features
 - Holes
 - Interfaces
- Numbers of fasteners
- Assembly method



We considered complexity of the design change and determined two paths of integrated cost analysis

- Automated analysis for simple (minor) changes
- Manual intervention for complex (major) changes

Connect Cost Modeling Tools to MBE Environment to inform design trades

Automated Cost Analysis (Minor Trade)

Prior to executing trade study analyses

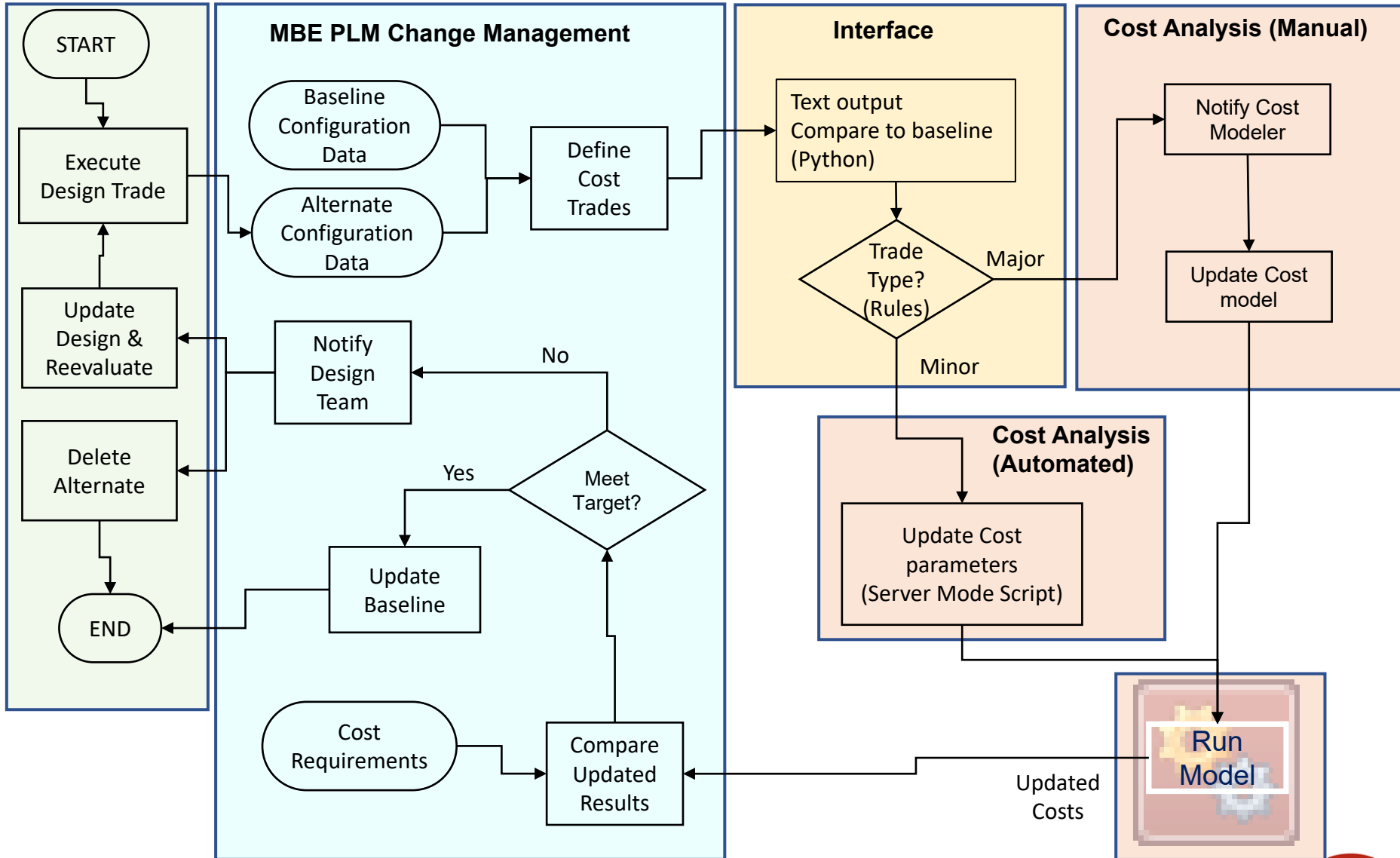
- MBE PLM system (CAMEO) contained baseline configuration data
- A baseline cost model was developed in SEER-MFG

To analyze the proposed change

- PLM system was updated with alternate configurations
- Data from the MBE PLM system passed to the Cost model
- Previously developed rules determined update method
- Cost model was updated (“reprogrammed”) via text files passed from PLM system containing changes
- Cost model was re-run via a Server Script (i.e. no user interface required) with the new inputs to determine the new cost
- Updated cost passed back to PLM system for evaluation

Automated

Integrated Cost-Design Trade Study Process



CAMEO Change Notification

The screenshot displays the Cameo software interface. On the left is a 'Containment' tree view showing a hierarchical structure of data categories such as Verification Data, Modeling & Simulation Data, Physical Data, Finance Data, Operational Data, Functional Data, Requirements Data, Affordability, Design Requirements, Interface Requirements, Verification Matrix, Certification Data, Logical Data, Safety Data, Modeling & Simulation Data, Conceptual Design Trade Study, Physical Data, and Finance Data. The 'Instances' folder is expanded, showing three configurations: 'Assembly - Configuration 1: Assembly', 'Assembly - Configuration 2: Assembly', and 'Assembly - Configuration 3: Assembly'. The 'Selected Instances' folder is also expanded, showing three instances: '1 - Importing from RI', '2 - Creating SYS Instance', and '3 - Selecting Material'. The main window displays a table of instances for '2 - Creating SYS Instance'. The table has columns for '#', 'Name', and various components like Bulkhead, Chord, Fitting, Frame, and Web. The table shows three rows of data, each representing a different configuration. The bottom of the table indicates that a filter is not applied and 3 rows are displayed.

#	Name	Bulkhead : Bulkhead	Chord : Chord	Fitting : Fitting	Frame : Frame	Web : Web	catia Wirefr Catia Wirefr
1	Assembly Configuration 1	Bulkhead_ComponentA : Bulkhead Bulkhead_ComponentB : Bulkhead Bulkhead_ComponentC : Bulkhead	LH_LChord : Chord LH_UChord : Chord RH_LChord : Chord RH_UChord : Chord	etmntFitting : Fitting r1Fitting : Fitting r2Fitting : Fitting r3r7Fitting : Fitting r4r8Fitting : Fitting	Frame_1 : Frame Frame_2 : Frame Frame_3 : Frame Frame_4 : Frame Frame_5 : Frame Frame_6 : Frame	LH_SideSkin : Web LowerWeb : Web RH_SideSkin : Web UpperWeb : Web	catia Wirefr Catia Wirefr
2	Assembly Configuration 2	Bulkhead_ComponentA : Bulkhead Bulkhead_ComponentB : Bulkhead Bulkhead_ComponentC : Bulkhead	LH_Lchord_2 : Chord LH_Uchord_2 : Chord RH_Lchord_2 : Chord RH_Uchord_2 : Chord	etmntFitting_2 : Fitting r1Fitting_2 : Fitting r2Fitting_2 : Fitting r3r7Fitting_2 : Fitting r4r8Fitting_2 : Fitting	Frame_1_2 : Frame Frame_2_2 : Frame Frame_3_2 : Frame Frame_4_2 : Frame Frame_5_2 : Frame Frame_6_2 : Frame	LH_SideSkin_2 : Web LowerWeb_2 : Web RH_SideSkin_2 : Web UpperWeb_2 : Web	catia Wirefr Catia Wirefr
3	Assembly Configuration 3	Bulkhead_ComponentA : Bulkhead Bulkhead_ComponentB : Bulkhead Bulkhead_ComponentC : Bulkhead	LH_Lchord_3 : Chord LH_Uchord_3 : Chord RH_Lchord_3 : Chord RH_Uchord_3 : Chord	etmntFitting_3 : Fitting r1Fitting_3 : Fitting r2Fitting_3 : Fitting r3r7Fitting_3 : Fitting r4r8Fitting_3 : Fitting	Frame_3_3 : Frame Frame_1_3 : Frame Frame_2_3 : Frame Frame_4_3 : Frame Frame_5_3 : Frame Frame_6_3 : Frame	LH_SideSkin_3 : Web LowerWeb_3 : Web RH_SideSkin_3 : Web UpperWeb_3 : Web	catia Wirefr Catia Wirefr

Various configurations explored via Cameo model

Launch Cost Analysis via Python

The screenshot displays a software interface with three main components:

- Model Tree (Left):** A hierarchical tree view showing various data categories such as Verification Data, Modeling & Simulation Data, Physical Data, Finance Data, Operational Data, Functional Data, Requirements Data, Affordability, Design Requirements, Interface Requirements, Verification Matrix, Certification Data, Logical Data, Safety Data, Modeling & Simulation Data, and Affordability Analysis Launching. The 'Affordability Analysis Launching' folder is expanded, showing multiple launch instances.
- Table (Center):** A table with columns for configuration details. The second row is selected. A context menu is open over this row with options: 'Evaluate Selected Rows' and 'Run Selected Rows with Behaviors'. An arrow points to this menu with the text 'Initiate Model Update'.
- Code Editor (Right):** A Python script snippet showing logic for different configurations. It uses `def` statements to define variables like `seerrfg`, `writer`, and `volumes`, and includes `println` statements for output. An arrow points to the code with the text 'Script passes info from Cameo to SEER'.

Annotations in the image:

- 'Select Configuration to analyze' points to the second row of the table.
- 'Initiate Model Update' points to the context menu over the second row.
- 'Script passes info from Cameo to SEER' points to the Python code blocks.

Script in Python to perform change detection of cost model inputs

Server Mode Script

The screenshot displays a software application window titled 'SEER-MFG'. The interface is divided into several sections:

- Menu Bar:** File, Home, Work Elements, Parameters, Tools, Reports, Charts, Export & Import, Options, Advanced, View.
- Work Elements Tree (Left):** A hierarchical list of elements including '1.2.2: Fram', '1.2.3: Bulk', '1.2.4: Bulk', and '1.2.5: Fram', with sub-items like 'SetUnits', 'SetSteppedLearning', 'SetExchangeRate', etc.
- Case2_Option1_Model.txt - Notepad (Center):** Contains project configuration details such as 'ProjectCreate Case 2 (Option 1)', 'SetUnits Imperial', 'SetBaseYear 2021', and 'SetFabPartBasedProcessing Off'.
- Data Table (Right):** A large table with multiple columns and rows, containing various parameters and their values. A text box 'populating Cost Model with Data from Cameo' is overlaid on this table.
- Charts (Bottom Left):** A section titled 'Cost Allocation' with a 'Work Elements' sub-section.
- Network (Bottom Center):** A small window showing '31 items 1 item selected 1.73 MB'.

The data table on the right includes the following content:

PRODUCT DESCRIPTION - Product Classification	VHI	VHI	VHI	16769216
PRODUCT DESCRIPTION - Program Type	Unclassified			
INSPECTION/REWORK				
INSPECTION/REWORK - In-Process Inspection	2.00%	2.00%	2.00%	16769216
INSPECTION/REWORK - In-Process Rework	2.00%	2.00%	2.00%	16769216
INSPECTION/REWORK - QA Inspection	5.00%	5.00%	5.00%	No 16769216
INSPECTION/REWORK - Rework	2.00%	2.00%	2.00%	No 16769216
LABOR CALIBRATION				
LABOR CALIBRATION - Prior Production Units	0			16769216
LABOR CALIBRATION - Stepped Learning				
LABOR CALIBRATION - Step 1	10,000		85.00%	16769216
LABOR CALIBRATION - Quantity (Step01)	10000			
LABOR CALIBRATION - Curve Percent (Step01)			85.00%	
ENGINEERING DESCRIPTION - Finished Assembly Size (sqin)	4214.83	4214.83	4214.83	
ENGINEERING DESCRIPTION - Number of Parts	24	24	24	
ENGINEERING DESCRIPTION - Total Length (in)	4330.60	4330.60	4330.60	
FITUP - Fastener Spacing (in)				
FITUP - Number of Fasteners	1,959	1,959	1,959	FALSE
FITUP - Temporary Fastener Percent	10.00%	10.00%	10.00%	
FITUP - Fitup Operation 1				
FITUP - Fitup Operation 1	Sub-Assembly	2	1	Locate Aid Jig Pins Load & Unload Nom YES
FITUP - Fitup Operation 2	Machined Part	24	1	Locate Aid Jig Pins Load & Unload Nom YES
FITUP - Fitup Operation 3	Detail 1	1	Locate Aid Jig Pins	Load & Unload Nom YES
FITUP - Fitup Operation 4	Detail 2	1	Locate Aid Jig Pins	Load & Unload Nom YES
FITUP - Clean, Seal and Bond 1	Faying Surface Sealing		100.00%	Nom No 600 52.19
FITUP - Down Time Percent	10.00%	10.00%	10.00%	
TOOL DESCRIPTION - Size Factor				
TOOL DESCRIPTION - Tool Length (in)	1.00	1.00	1.00	
TOOL DESCRIPTION - Tool Width (in)	0.00	0.00	0.00	
TOOL DESCRIPTION - Tool Area (sqin)	0.00	0.00	0.00	
TOOL DESCRIPTION - Number of Tool Parts 1	1	1		
TOOL DESCRIPTION - Number of Accessories	0	0	0	
TOOL DESCRIPTION - Tool Complexity	Low	Low	Low	
TOOL DESCRIPTION - Tool Prep	Yes			
TOOL DESCRIPTION - Clean, Package & Store	Yes			
TOOL DESCRIPTION - Initial Tool Fabrication & Design	No			
MANUFACTURING DESCRIPTION - Mechanization	Low+	Nom	Hi-	
MANUFACTURING DESCRIPTION - Accessibility	Nom+	Hi	Hi	
MANUFACTURING DESCRIPTION - Material Utilization Factor	1.00	1.10	1.20	
MANUFACTURING DESCRIPTION - Program Load Time (min)	10.00	10.00	10.00	Yes
MANUFACTURING DESCRIPTION - Primary Set-up (min)	235.774	235.774	235.774	TRUE
MANUFACTURING DESCRIPTION - Unload Assembly (min)	172.631	172.631	172.631	TRUE
PROBABILITY (RISK)	50.00%	16769216		
FINANCIAL FACTORS				

Command Line to by-pass GUI interface and to automate cost analyses

Verify Cost Requirements

Criteria

Classifier: Affordability Analysis Launching Scope (optional): Concept

Excel Import Status: New Updated Obsolete Unchanged

#	Name	Average Pylon Manufacturing : Real	Average Production Unit recurring manufacturing cost : Average Production Unit recurring manufacturing cost
1	Assembly - Configuration 1	10 0000.00	pass
2	Assembly - Configuration 2	2 00000.00	fail
3	Assembly - Configuration 3	12 00000.00	pass

Cost Requirements verified in Cameo

Cost Results passed back to Cameo

Filter is not applied. 22 rows are displayed in the table.

Notional results for presentation

Summary and Next Steps

Objective: Integrate cost models into MBE

- Enable rapid exploration of cost impacts of design trades, concurrent with other change activity

Progress to date

- Demonstrated a means to quickly, effectively and automatically determine cost impacts of proposed changes inside an MBE environment
- Focused on automated (minor) updates to cost models
 - Without manual intervention

Next Steps

- Integrate cost analysis of major design trades to provide timely feedback to design teams
- Evaluate integration of additional cost modeling methods and tools