“Virtual Manufacturing Frontier” Path-Forward

AMMEP Planning Workshop
Georgia Institute of Technology
September 15, 2011

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Chairman NDIA AMEC Committee

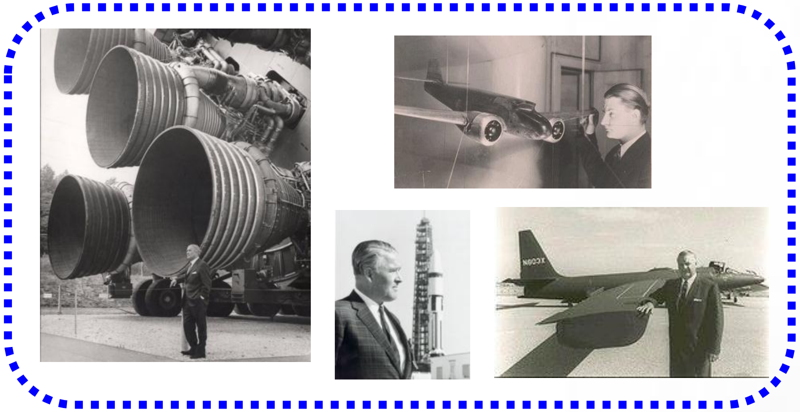
The World has Changed.....

	20th century paradigms	21st century realities
INDUSTRIAL BASE	Orig Equip Manuf (OEM)	System integrators
	Domestic industrial bases	A global industrial base
	Static supply chains	Dynamic supplier networks
	We design what we build	We design what others build
DESIGN ENVIROMENT	Large complex systems	Larger systems of systems
	Discipline centric designs	Cyber-electro-mech designs
	Collocated design teams	Collaborative virtual teams
	Paper-based environments	Model-based environments
BUSINESS MODELS	Learn by experimentation	Learn virtually by simulation
	Balancing handful of "ilities"	Trading off 80+ "ilities"
	Technology at any cost	Cost is a key requirement
	Profit on the aftermarket	Minimize life cycle costs

Cost is the new King of the A&D Industry

Our Culture Hasn't….

- **Engineering invents and creates….**
  - **Rocket scientists and engineers dream up new technologies**
  - **Mathematical and scientific principles used to solve problems**
  - **Performance enhancing technologies developed at any cost**
- **Manufacturing builds and mass produces….**
  - **Semi-skilled labor uses machine tools and jigs to make parts**
  - **Experience and judgment used to develop/optimize processes**
  - **Automation and lean used to make processes more efficient**

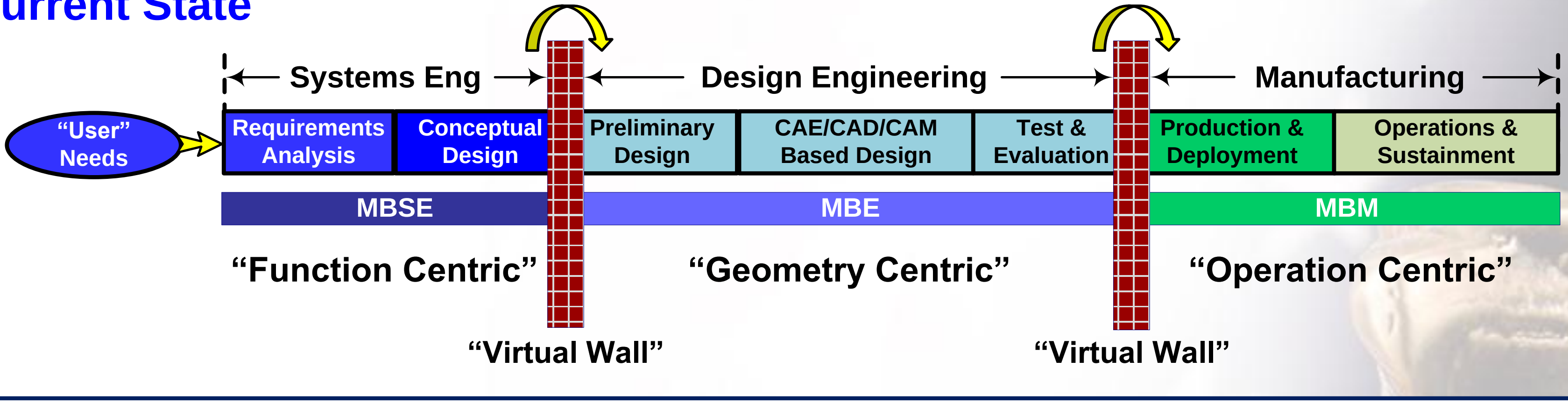


Need to Change a Century of Perceptions

National Defense Industrial Association

Changing the Paradigm

Current State



Systems Eng
Design Engineering
Manufacturing

"User" Needs

Requirements Analysis
Conceptual Design
Preliminary Design
CAE/CAD/CAM Based Design
Test & Evaluation
Production & Deployment
Operations & Sustainment

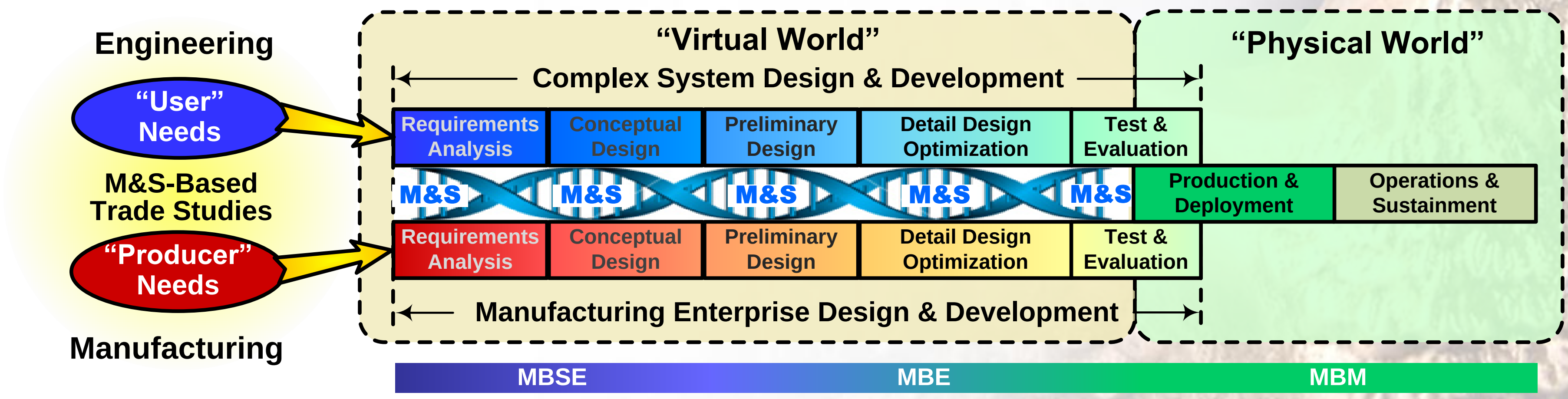
MBSE
MBE
MBM

"Function Centric"
"Geometry Centric"
"Operation Centric"

"Virtual Wall"
"Virtual Wall"

Transforming the Design Space

Future State



"Fit-Form-Function-Operation Centric"

Engineering

"User" Needs

M&S-Based Trade Studies

"Producer" Needs

Manufacturing

"Virtual World"

Complex System Design & Development

Requirements Analysis
Conceptual Design
Preliminary Design
Detail Design Optimization
Test & Evaluation

M&S
M&S
M&S
M&S
M&S

"Physical World"

Production & Deployment
Operations & Sustainment

Requirements Analysis
Conceptual Design
Preliminary Design
Detail Design Optimization
Test & Evaluation

Manufacturing Enterprise Design & Development

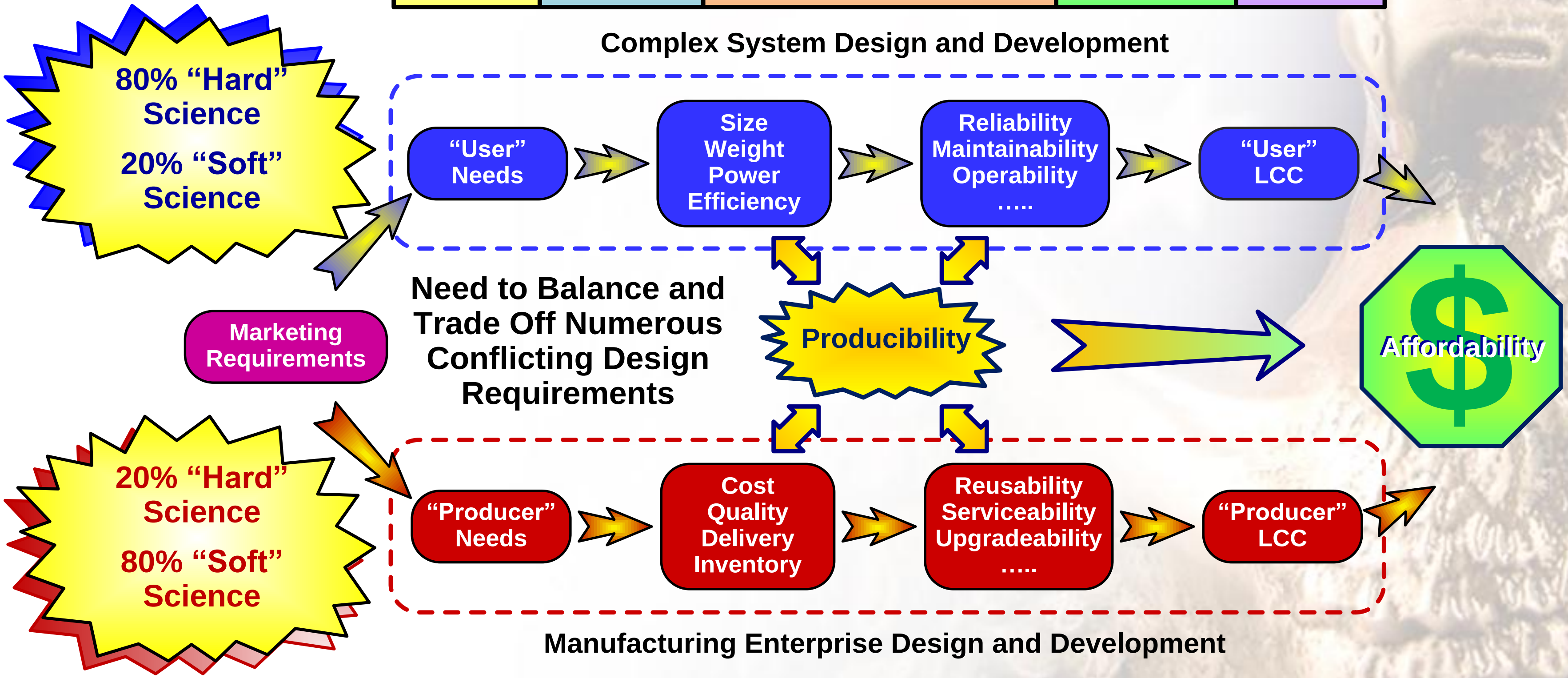
MBSE
MBE
MBM

"Re-Engineering" Design & Manufacturing

Producibility Trade Space Focus

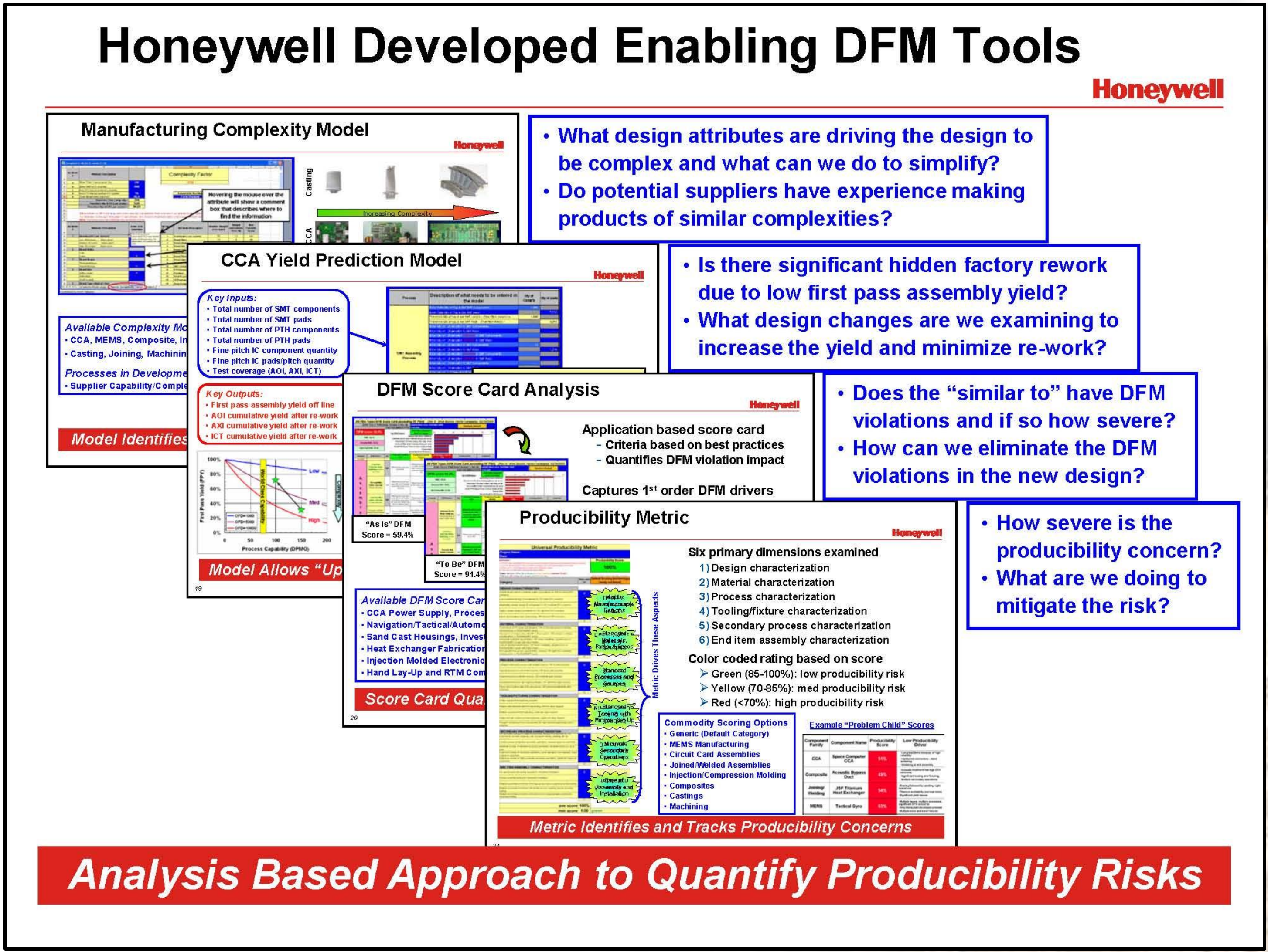
AMEC M&S Focus
“Fuzzy Front-End”

Concept Design	Preliminary Design	Component Detail Design & Manuf Process Development	Production & Deployment	Operations & Support



Producibility “Kingpin” of Affordability

Example Producibility Design Tools



Honeywell Developed Enabling DFM Tools

Manufacturing Complexity Model

Hovering the mouse over the attribute will show a comment box that describes where to find the information

Available Complexity Mo
- CCA, MEMS, Composite, In
- Casting, Joining, Machinin

Processes in Developme
- Supplier Capability/Comple

Model Identifies

CCA Yield Prediction Model

Key Inputs:
- Total number of SMT components
- Total number of SMT pads
- Total number of PTH components
- Total number of PTH pads
- Fine pitch IC component quantity
- Fine pitch IC pads/pitch quantity
- Test coverage (AOI, AXI, ICT)

Key Outputs:
- First pass assembly yield off line
- AOI cumulative yield after re-work
- AXI cumulative yield after re-work
- ICT cumulative yield after re-work

Model Allows "Up

DFM Score Card Analysis

Application based score card
- Criteria based on best practices
- Quantifies DFM violation impact

Captures 1st order DFM drivers

"As Is" DFM Score = 59.4%

"To Be" DFM Score = 91.4%

Available DFM Score Car
- CCA Power Supply, Proces
- Navigation/Tactical/Autom
- Sand Cast Housings, Invest
- Heat Exchanger Fabrication
- Injection Molded Electronic
- Hand Lay-Up and RTM Com

Score Card Qua

Producibility Metric

Six primary dimensions examined
1) Design characterization
2) Material characterization
3) Process characterization
4) Tooling/fixture characterization
5) Secondary process characterization
6) End item assembly characterization

Color coded rating based on score
- Green (85-100%): low producibility risk
- Yellow (70-85%): med producibility risk
- Red (<70%): high producibility risk

Commodity Scoring Options
- Generic (Default Category)
- MEMS Manufacturing
- Circuit Card Assemblies
- Joined/Welded Assemblies
- Injection/Compression Molding
- Composites
- Castings
- Machining

Example "Problem Child" Scores

Metric Identifies and Tracks Producibility Concerns

- What design attributes are driving the design to be complex and what can we do to simplify?
- Do potential suppliers have experience making products of similar complexities?

- Is there significant hidden factory rework due to low first pass assembly yield?
- What design changes are we examining to increase the yield and minimize re-work?

- Does the "similar to" have DFM violations and if so how severe?
- How can we eliminate the DFM violations in the new design?

- How severe is the producibility concern?
- What are we doing to mitigate the risk?

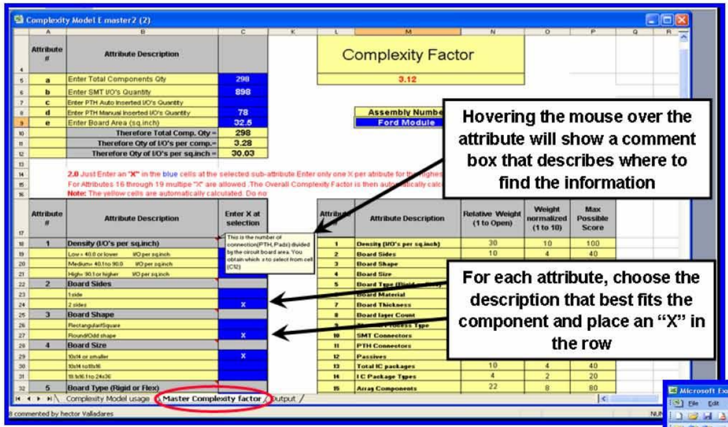
Analysis Based Approach to Quantify Producibility Risks

Source: A. Sanders, "Modeling & Simulation Approaches for Conceptual Design Producibility Trades", Presented at the annual Defense Manufacturing Conference (DMC), Orlando, Florida, Dec. 1-4, 2008.

Example Producibility Design Tools

Manufacturing Complexity Model

Honeywell



Complexity Model E master2 (2)

Attribute #	Attribute Description	
a	Enter Total Components Qty	298
b	Enter SMT I/O's Quantity	898
c	Enter PTH Auto Inserted I/O's Quantity	
d	Enter PTH Manual Inserted I/O's Quantity	78
e	Enter Board Area (sq.inch)	32.5
	Therefore Total Comp. Qty =	298
	Therefore Qty of I/O's per comp.=	3.28
	Therefore Qty of I/O's per sq.inch =	30.03

Complexity Factor

3.12

Assembly Number

Ford Module

2.0 Just Enter an "X" in the blue cells at the selected sub-attribute Enter only one X per atribute for th… highes…

For Attributes 16 through 19 multipe "X" are allowed .The Overall Complexity Factor is then auto…tically calc…

Note: The yellow cells are automatically calculated. Do no

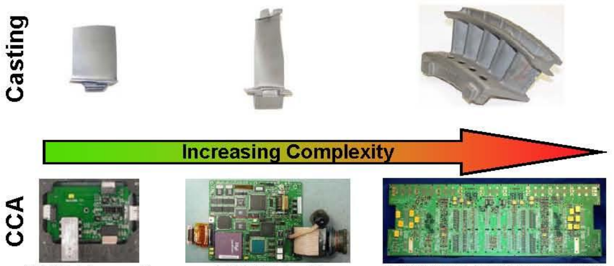
Attribute #	Attribute Description	Enter X at selection
1	Density (I/O's per sq.inch)	
	Low = 40.0 or lower I/O per sq.inch	
	Medium= 40.1 to 90.0 I/O per sq.inch	
	High= 90.1 or higher I/O per sq.inch	
2	Board Sides	
	1 side	
	2 sides	X
3	Board Shape	
	Rectangular/Square	
	Round/Odd shape	X
4	Board Size	
	10x14 or smaller	X
	10x14 to 18x16	
	18.1x16.1 to 24x36	
5	Board Type (Rigid or Flex)	

This is the number of connection(PTH, Pads) divided by the circuit board area. You obtain which x to select from cell (C12)

Attribute #	Attribute Description	Relative Weight (1 to Open)	Weight normalized (1 to 10)	Max Possible Score
1	Density (I/O's per sq.inch)	30	10	100
2	Board Sides	10	4	40
3	Board Shape			
4	Board Size			
5	Board Type (Rigid or Flex)			
6	Board Material			
7	Board Thickness			
8	Board layer Count			
9	Thermal Process Type			
10	SMT Connectors			
11	PTH Connectors			
12	Passives			
13	Total IC packages	10	4	40
14	I C Package Types	4	2	20
15	Array Components	22	8	80

Hovering the mouse over the attribute will show a comment box that describes where to find the information

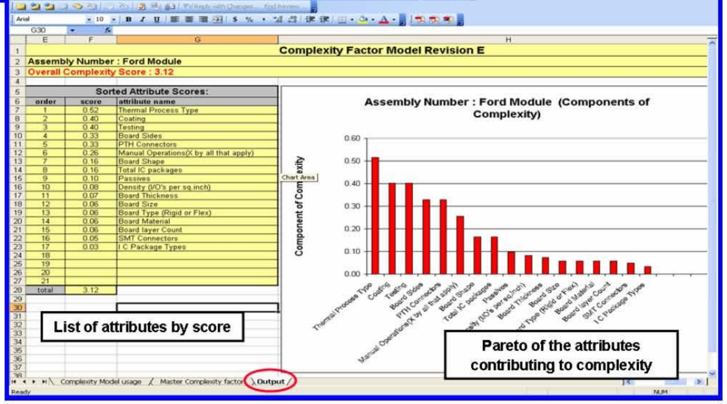
For each attribute, choose the description that best fits the component and place an "X" in the row



.063" thick one side passives with 0.050" pitch IC's and PTH connectors

0.090" thick with passives, 1.27 BGA , Fine pitch PEM, PTH connectors, jumper wires

0.400" thick, 1400 components, double sided, SMT Ceramic Flat packs, 7 PTH connectors, 16 Press-fit in connectors



Microsoft Excel - Complexity Model E master2

Complexity Factor Model Revision E

Assembly Number : Ford Module

Overall Complexity Score : 3.12

Sorted Attribute Scores:

order	score	attribute name
1	0.52	Thermal Process Type
2	0.40	Coating
3	0.40	Testing
4	0.33	Board Sides
5	0.33	PTH Connectors
6	0.26	Manual Operations(X by all that apply)
7	0.16	Board Shape
8	0.16	Total IC packages
9	0.10	Passives
10	0.08	Density (I/O's per sq.inch)
11	0.07	Board Thickness
12	0.06	Board Size
13	0.06	Board Type (Rigid or Flex)
14	0.06	Board Material
15	0.06	Board layer Count
16	0.05	SMT Connectors
17	0.03	I C Package Types
18		
19		
20		
21		
total	3.12	

List of attributes by score

Pareto of the attributes contributing to complexity

Available Complexity Models

- CCA, MEMS, Composite, Injection Molding
- Casting, Joining, Machining

Processes in Development

- Supplier Capability/Complexity Alignment

Model Identifies Top Design Simplification Opportunities

Source: A. Sanders, "Modeling & Simulation Approaches for Conceptual Design Producibility Trades", Presented at the annual Defense Manufacturing Conference (DMC), Orlando, Florida, Dec. 1-4, 2008.

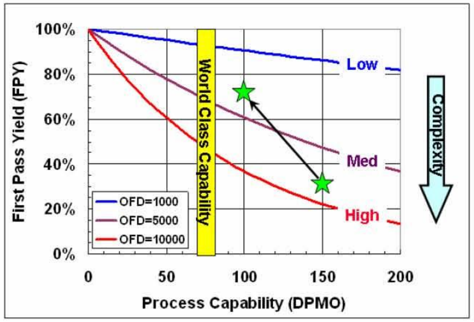
Example Producibility Design Tools

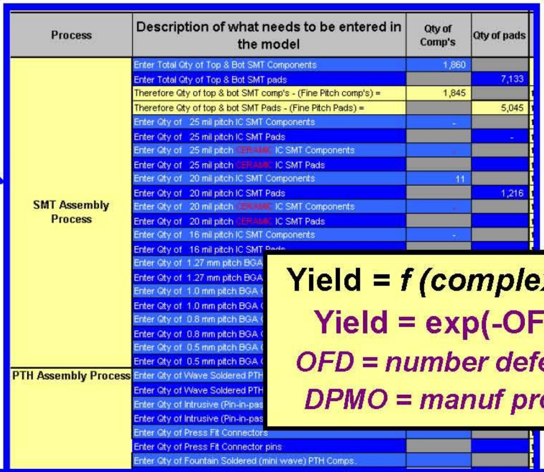
CCA Yield Prediction Model

Honeywell

Key Inputs:
- Total number of SMT components
- Total number of SMT pads
- Total number of PTH components
- Total number of PTH pads
- Fine pitch IC component quantity
- Fine pitch IC pads/pitch quantity
- Test coverage (AOI, AXI, ICT)

Key Outputs:
- First pass assembly yield off line
- AOI cumulative yield after re-work
- AXI cumulative yield after re-work
- ICT cumulative yield after re-work





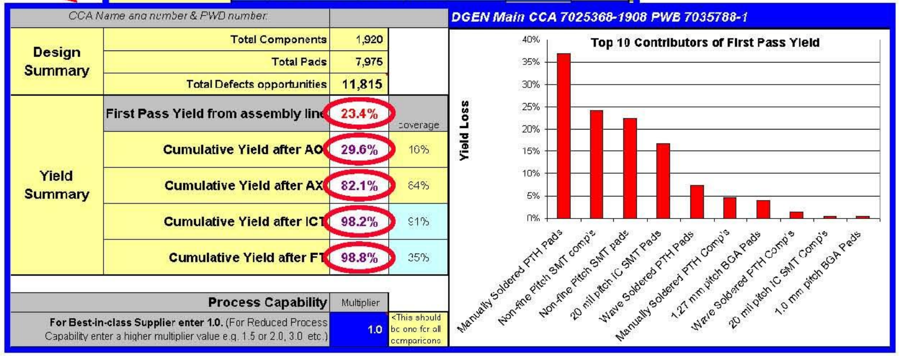
Process	Description of what needs to be entered in the model	Qty of Comp's	Qty of pads
SMT Assembly Process	Enter Total Qty of Top & Bot SMT Components	1,860	
	Enter Total Qty of Top & Bot SMT pads		7,133
	Therefore Qty of top & bot SMT comp's - (Fine Pitch comp's) =	1,845	
	Therefore Qty of top & bot SMT Pads - (Fine Pitch Pads) =		5,045
	Enter Qty of 25 mil pitch IC SMT Components	-	
	Enter Qty of 25 mil pitch IC SMT Pads		-
	Enter Qty of 25 mil pitch CERAMIC IC SMT Components		
	Enter Qty of 25 mil pitch CERAMIC IC SMT Pads		
	Enter Qty of 20 mil pitch IC SMT Components	11	
	Enter Qty of 20 mil pitch IC SMT Pads		1,216
	Enter Qty of 20 mil pitch CERAMIC IC SMT Components		
	Enter Qty of 20 mil pitch CERAMIC IC SMT Pads		
	Enter Qty of 16 mil pitch IC SMT Components	-	
	Enter Qty of 16 mil pitch IC SMT		
	Enter Qty of 1.27 mm pitch BGA		
	Enter Qty of 1.27 mm pitch BGA		
	Enter Qty of 1.0 mm pitch BGA		
	Enter Qty of 1.0 mm pitch BGA		
	Enter Qty of 0.8 mm pitch BGA		
	Enter Qty of 0.8 mm pitch BGA		
	Enter Qty of 0.5 mm pitch BGA		
	Enter Qty of 0.5 mm pitch BGA		
PTH Assembly Process	Enter Qty of Wave Soldered PTH		
	Enter Qty of Wave Soldered PTH		
	Enter Qty of Intrusive (Pin-in-pas		
	Enter Qty of Intrusive (Pin-in-pas		
	Enter Qty of Press Fit Connectors		
	Enter Qty of Press Fit Connector pins		
	Enter Qty of Fountain Soldered (mini wave) PTH Comps.		

Yield = *f (complexity, capability)*

$$\mathrm{Yield} = \exp(-\mathrm{OFD}*\mathrm{DPMO}/10^{6})$$

OFD = number defect opportunities

DPMO = manuf process capability



CCA Name and number & PWD number:			
Design Summary	Total Components	1,920	
	Total Pads	7,975	
	Total Defects opportunities	11,815	
Yield Summary	First Pass Yield from assembly line	23.4%	coverage
	Cumulative Yield after AO	29.6%	16%
	Cumulative Yield after AX	82.1%	64%
	Cumulative Yield after ICT	98.2%	91%
	Cumulative Yield after FT	98.8%	35%
	Process Capability	Multiplier	
	For Best-in-class Supplier enter 1.0. (For Reduced Process Capability enter a higher multiplier value e.g. 1.5 or 2.0, 3.0 etc.)	1.0	<This should be one for all comparisons

DGEN Main CCA 7025368-1908 PWB 7035788-1

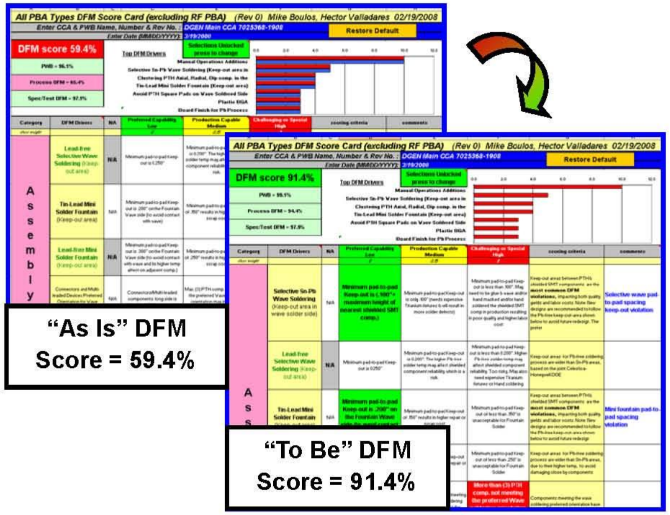
Model Allows "Up-Front" Prediction of CCA Yield Targets

Source: A. Sanders, "Modeling & Simulation Approaches for Conceptual Design Producibility Trades", Presented at the annual Defense Manufacturing Conference (DMC), Orlando, Florida, Dec. 1-4, 2008.

Example Producibility Design Tools

DFM Score Card Analysis

Honeywell



All PBA Types DFM Score Card (excluding RF PBA) (Rev 0) Mike Boulos, Hector Valladares 02/19/2008

Enter CCA & PWB Name, Number & Rev No. : DGEN Main CCA 7025368-1908

Restore Default

DFM score 59.4%

DFM score 91.4%

"As Is" DFM
Score = 59.4%

"To Be" DFM
Score = 91.4%

Available DFM Score Cards

- CCA Power Supply, Processor/IO/Analog, RF
- Navigation/Tactical/Automotive Grade MEMS
- Sand Cast Housings, Investment Cast Vanes
- Heat Exchanger Fabrication and Joining
- Injection Molded Electronic Enclosures
- Hand Lay-Up and RTM Composites

Application based score card
  - Criteria based on best practices
  - Quantifies DFM violation impact

Captures 1st order DFM drivers
  - Key design & process attributes
  - Differentiates violation severity

Three producibility classes
  - "Green" : preferred capability mild concerns: score > 85%
  - "Yellow" : challenging capability moderate concerns: score 70-85%
  - "Red" : limited/special capability significant concerns: score < 70%

Score Card Quantifies DFM Goodness of Design Concept

Source: A. Sanders, "Modeling & Simulation Approaches for Conceptual Design Producibility Trades", Presented at the annual Defense Manufacturing Conference (DMC), Orlando, Florida, Dec. 1-4, 2008.

Fundamental Research Thrusts

- **Analytical tools to quantify and predict producibility**
- **Methods to define, allocate, flow down producibility rqmts**
- **Prediction of theoretical process capability thresholds**
- **Design methodologies that cope with uncertainty and risk**
- **Design decision aides to cope with scale and complexity**
- **Architecture design approaches that allow adaptability**
- **Frameworks that make the exploding state space tractable**
- **Supply chain “design and analysis” methods and tools**
- **Benchmark experimental data sets to validate M&S tools**

Roadmaps to Define Intersection of Thrusts with Each of the Six Focus Areas

Next Steps in the Journey

- **Cultural – changing paradigms….**
  - **Redefining the boundary between engineering & manufacturing**
  - **Not letting current methods and tools constrain our thinking**
  - **Make advanced manufacturing a core “engineering” discipline**
- **Technical - developing roadmaps….**
  - **Leverage industry team to identify critical gaps and needs**
  - **Leverage academia to develop solutions to reach future state**
  - **Invitation only think-tank/workshop of SME’s to draft roadmaps**
- **Policy/Funding - finding sponsors….**
  - **Make developing new design methodologies a research priority**
  - **Influencing S&T investments to include manufacturing M&S**
  - **Industry-government-academia collaboration key to success**

Continue to Build Critical Mass & Support

AMEC M&S White Paper

- **Based on 18 month study on current DFM practices***
  - **Analytical producibility analysis tools lacking**
  - **Many producibility issues inadvertently designed-in**
  - **Current commercial DFM analysis tools inadequate**
  - **Manufacturing M&S a critical missing research area**
- **Roadmap development underway for key focus areas**
  - **Systems engineering trade study and design methodologies**
  - **System integration, assembly, and test modeling**
  - **Enterprise level supply chain design and analysis methods**
  - **Electrical, mechanical, and assembly yield modeling**
  - **Quantitative DFX analyses including complexity characterization**
  - **Life cycle cost modeling including uncertainty and risk impact**

*NDIA Manufacturing Division White Paper, “21st Century Manufacturing Modeling & Simulation Research and Investment Needs,” Released May 2011.

Maintain Focus on Critical Few Areas

AMEC M&S Roadmap Scope

"Identify industry ***M&S analysis*** needs to facilitate the integration of ***producibility*** considerations into the earliest phases of the system engineering process for complex ***aerospace and defense*** system design"

- **In-Scope**
  - **Product & process centric analyses to guide design decisions**
  - **Factory & supply chain analyses to guide industrial base design**
  - **Methods to integrate producibility into early SE trade studies**

- **Out of Scope**
  - **Development of M&S data standards & interoperability rqmts**
  - **Virtual collaboration tools and enhancements to existing SW**
  - **IT-enabled PLM software and modeling language improvements**

Limit Scope to M&S "Analysis" Capabilities and "Design Methods"

Thank You
Questions?