Modeling & Simulation Investment
Needs for Producible Designs and Affordable Manufacturing

Systems Engineering Implications

NDIA JCSEM M&S Sub-Committee
Dr. Al Sanders (Chair)
April, 2010
JCSEM M&S Sub-Committee Members

- Joint Committee for Systems Engineering & Manufacturing
  - Sponsored by NDIA Systems Engineering & Manufacturing Divisions
  - Chaired by Dr. Tom Christian (SE) and Mike Packer (Manufacturing)

- JCSEM M&S Sub-Committee Chartered in November 2008
  - Dr. Al Sanders – Chairman (Honeywell)
  - John Allen (Honeywell)
  - Kevin Fischer (Rockwell Collins)
  - Greg Pollari (Rockwell Collins)
  - Charlie Stirk (Cost Vision)
  - Dr. Gary Belie (LMCO)
  - Simon Frechette (NIST)
  - Tim Comerford (Missouri University of S&T)
  - Scott Frost (Anser)
  - Brench Boden (AFRL)
Current State of Producibility M&S

- Many producibility issues driven by early SE & design decisions
  - Producibility forgotten requirement
  - Producibility hard to quantify early
  - Producibility M&S tools immature

- Most producibility analyses are CAD-based rule checkers
  - Require nearly final design layout
  - Occur too late to influence design
  - Only as good as rules loaded in

- Need quantitative low & high-fidelity tools for trade studies
  - Balance performance/producibility
  - Guide analysis-based decisions
  - Shape design vs. verify problems

**Void Exists in Current Producibility M&S Capabilities**
“Identify industry M&S analysis needs to facilitate the integration of producibility concerns into the earliest phases of the system engineering process”

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

Out-of-Scope:
- Virtual collaboration tools and enhancements to existing software
- Data standards, protocols, and interoperability requirements
- Digital/IT type solutions to facilitate information sharing

*Focus was Identifying M&S Needs that do not Exist Today*
Objectives and Focus Areas:

- Identification of product, process, and supply chain analysis needs
- Develop a producibility figure of merit “goodness” measure
- Identification of viable approaches for SE trade study integration

Technical Approach:

- Define the key inputs that would go into a producibility figure of merit calculation to capture and quantify producibility concerns
- Define specific M&S focus areas where producibility analysis capabilities are needed to support system design activities
- Define what type of information the analyses should provide at each step in the system design and development process
- Evaluate potential trade study approaches for ease of integrating producibility considerations into early system design activities

All Sub-Committee Objectives met and/or Exceeded
Producibility Figure of Merit Elements

- Producibility definition used by sub-committee:
  - Producibility defined as ease and economy of manufacturing an item, or group of items, in large quantities in a production environment
  - Most producibility costs “hidden” in nature such as scrap, rework, missed deliveries, safety stock, and lead time buffers due to low yield

<table>
<thead>
<tr>
<th>System Producibility Elements</th>
<th>Key Factory Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prod. Score: ( Y = f(x_1, x_2, \ldots, x_n) )</td>
<td>Cost</td>
</tr>
<tr>
<td>( x_1 ) Unit Product Cost (Material &amp; Conversion)</td>
<td>X</td>
</tr>
<tr>
<td>( x_2 ) Manufacturing Capital Investment Cost &amp; Risk</td>
<td>X</td>
</tr>
<tr>
<td>( x_3 ) Development MRL Maturation Cost &amp; Risk</td>
<td>X</td>
</tr>
<tr>
<td>( x_4 ) Overall Manufacturing Cycle Time (WSCT)</td>
<td></td>
</tr>
<tr>
<td>( x_5 ) Item Scrap &amp; Rework (COPO)</td>
<td>X</td>
</tr>
<tr>
<td>( x_6 ) Item Rate &amp; Shipment Risks (OTTR)</td>
<td></td>
</tr>
<tr>
<td>( x_7 ) Item Assembly, Test, &amp; Integration Complexity</td>
<td></td>
</tr>
<tr>
<td>( x_8 ) Item Long Term Sustainability Risks</td>
<td>X</td>
</tr>
</tbody>
</table>

Legend:
- Manufacturing Cost Currently Considered
- Manufacturing Cost not Currently Considered
- Hidden Factory Cost not Currently Considered

Weight factors would be assigned to each element of the figure of merit based on relative cost impact and risk for critical systems, sub-systems, & components

Figure of Merit Links Producibility to Key Factory Metrics
Matrix focus areas:

- Should cost analyses
- Yield prediction models
- Design for “X” analyses
- Obsolescence modeling
- Manuf process modeling
- Production line modeling
- System integration, assembly, & test modeling
- Operator assembly & test modeling, e.g., ergonomics
- Physics based analyses (casting, solder flow, etc.)

M&S Analysis Output for each Design Phase Identified

- Identification of critical components driving yield fallout
- Identification of design simplification and yield improvement opportunities
- Prediction of component variation impact on yield
- Prediction of test coverage overlap impact due to multiple assembly processes
- Prediction of DFM violation impact on yield fallout
- Prediction of yield fallout due to supplier process capability variability
- Analysis of component type and processing alternatives on yield
- Analysis of component yield classification (reworkable vs. scrap)
Supply Chain Design & Analysis

Analysis focus areas:

- **Distribution aspects**
  - Infrastructure complexity
  - Contract/policy constraints
  - Logistics/queuing delays
  - Environmental events

- **Technical aspects**
  - Product complexity
  - Material availability/maturity
  - Process learning curves
  - Technology maturity
  - Work force maturity
  - Sustainability impact
  - Business strategy alignment
  - Trend analysis & diagnostics

System Modeling Approach for Industrial Base Design
**Producibility M&S Linkage**

<table>
<thead>
<tr>
<th>Producibility Life Cycle Cost Drivers</th>
<th>Product, Process, &amp; Supply Chain Producibility Analysis Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Manufacturing Cycle Time (WSCT)</td>
<td></td>
</tr>
<tr>
<td>Item Scrap &amp; Rework (COPQ)</td>
<td></td>
</tr>
<tr>
<td>Item Rate &amp; Shipment Risks (OTTR)</td>
<td></td>
</tr>
<tr>
<td>Item Assembly, Test, &amp; Integration Complexity</td>
<td></td>
</tr>
<tr>
<td>Item Long Term Sustainability Risks</td>
<td></td>
</tr>
<tr>
<td>Development MRL Maturation Cost &amp; Risk</td>
<td></td>
</tr>
<tr>
<td>Manufacturing Capital Investment Cost &amp; Risk</td>
<td></td>
</tr>
</tbody>
</table>

Legend:
- **Green**: Manufacturing Cost Currently Considered
- **Blue**: Manufacturing Cost not Currently Considered
- **Yellow**: Hidden Factory Cost not Currently Considered

Weight factors would be assigned to each element of the figure of merit based on relative cost impact and risk for critical systems, sub-systems, & components.

**Producibility Figure of Merit Integrates M&S Tool Output into a Single “Goodness” Measure for Trade Evaluations**
SE Trade Study Integration

- Manufacturing VOC to be included in trade study process
  - Responsible for long-term production of the proposed system
  - Provides input on production cost, quality, delivery, & inventory goals
  - Establishes process capability, cycle time, and yield flow down targets

- Quality Function Deployment (QFD) based methods
  - Most common trade study tool to down select alternative concepts
  - Help translate customer needs into system specs and design criteria
  - Correlate key technical performance measures to acquisition cost
  - Mature approach that can be easily adapted to include producibility

- Value Driven Design (VDD) based methods
  - Integrates systems engineering, optimization, and economic principles
  - Leverages requirements flexibility, optimization, and value models
  - Helps balance among competing TPM’s to produce best system offering
  - Emerging research area that addresses limitations of QFD approaches

Producibility M&S Capability Enables Trade Integration
DoD and Industry Benefits

• Several GAO studies conducted around acquisition cost overruns
  - Systemic issue was excessive design, technology, & manufacturing risk
  - Successful programs exhibited earlier design & producibility knowledge
  - Recommendation is adoption of knowledge-based decision processes

• Producibility analysis capability generates critical knowledge early
  - Provides means to influence and validate requirements feasibility
  - Provides means to identify, quantify, and proactively plan for risk
  - Provides manufacturing analysis capability comparable to engineering

• Producibility figure of merit provides means to quantify concerns
  - Provides means to quantify “hidden costs” during early design studies
  - Provides means to guide industrial base solutions and minimize risk
  - Provides means to down select most producible design alternatives

*Producibility M&S Enabler for Early Knowledge Integration*
Summary & Recommendations

- Producibility is neglected “ility” due to lack of analysis capability
  - Producibility issues are difficult to predict and drive “hidden” costs
  - Manufacturing VOC needs to be included in requirements definition
  - SE trade studies need to incorporate producibility considerations

- Producibility M&S is a critical research area that has been missing
  - M&S tools required to drive manufacturing to left in acquisition
  - Product, process, & supply chain centric analyses are needed
  - Requires focused research attention and investments to mature

- Top level framework established for SE trade study integration
  - Producibility figure of merit developed as “goodness” measure
  - Current QFD-based methods can be extended to address producibility
  - More research is needed to develop and mature VDD-based approaches

Final Report Documents Committee Recommendations