Advanced Engineering Environments for Small Manufacturing Enterprises

Joseph P. Elm

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**Report Documentation Page**

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Introduction

The future of manufacturing includes supply chain integration.

Advanced Engineering Environments (AEEs) will play a pivotal role in this integration.

Integration of Small Manufacturing Enterprises (SMEs) into the supply chain is a significant challenge.

• SMEs face unique challenges in adopting AEEs
Agenda

Context of Research

Small Manufacturing Enterprises (SMEs)

Advanced Engineering Environments (AEEs)

AEE Adoption Benefits

AEE Adoption Challenges

Summary
Agenda

Context of Research

Small Manufacturing Enterprises (SMEs)

Advanced Engineering Environments (AEEs)

AEE Adoption Benefits

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Summary
Context of Research

**Sponsor**
Technology Insertion, Demonstration, and Evaluation (TIDE) Program

**Objective**
“…demonstrate the cost savings and efficiency benefits of applying commercially available software and information technology to the manufacturing lines of small defense firms.”

**Participants**
- Software Engineering Institute, Carnegie Mellon University
- NIST – Manufacturing Engineering Laboratory
- Oversight by DoD ManTech

TIDE - risk reduction, proof of feasibility for SMEs
TIDE Overview/Strategy

TECHNOLOGY DEVELOPMENT

(OCTAVESM-S, Advanced Engineering Environments (AEE), CMMI® for SMEs)

DEMONSTRATION PROJECTS

• Early Demo Projects (Core Insertions)
• Advanced Demo Projects

• Lessons Learned
• Technology Adaptations
• Publications
• Barrier Identification
• Vendor Impact

Body of Knowledge - Support for SMEs

WORKFORCE DEVELOPMENT

• IT Prof. Development series
• Selected SEI Courses
• Tech Adoption Workshops
• New courses and training

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Small Manufacturing Enterprises

Who are they?
- <750 employees
- Not software centric
- Most <250 employees
- Short term focus

Why focus on SMEs?
• Critical to the US economy
  - Manufacturing comprises 14% of the US GDP
    – That’s $1.4 TRILLION \(\text{BEA, US Dept. of Commerce}\)
  - 98% of US manufacturing firms are SMEs employing 41% of the manufacturing workforce \(\text{U.S. Small Business Administration}\)

• Critical to US Defense
  - Primes concentrating on core VALUE ADDED activities
    – PM, System Engineering, System Integration
  - >80% of production of some weapons system is outsourced

OPPORTUNITY CHALLENGE FOR SMALL MANUFACTURERS !!!
SME Community Stress Factors

Increasing global competition

Aging workforce and ownership

Expanding technology options

Changing Needs of the DoD
  • Dual use components and systems
  • Increasing supply chain integration
  • Rate transparent production
  • Surge production capacity
  • Rapid product realization
SME Community Stress Factors

Increasing global competition

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Expanding technology options

Changing Needs of the DoD

- Dual use components and systems
- Increasing supply chain integration
- Rate transparent production
- Surge production capacity
- Rapid product realization

Potential to drive many SMEs out of business
What Does this Mean for SMEs?

**SMEs are more tightly integrated with the Primes**
- Not just component build-to-print
- Participate in Product Development, Inventory Management, Quality Improvement, and Life Cycle Cost Reduction

**New demands upon the SME**
- Expanded design and engineering capabilities
- Improved technical and project data communication
- Enhanced process management and control
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AEEs can help
Advanced Engineering Environments

AEEs are …
“… computational and communications systems that can create virtual and/or distributed environments functioning to link researchers, technologists, designers, manufacturers, suppliers, and customers.” [NRC 99]

AEEs consist of
- Design tools
  - computer-aided design (CAD)
  - computer-aided engineering (CAE)
- Production tools
  - computer-aided manufacturing (CAM)
- Project management tools
- Data repositories
  - product data management (PDM)
- Networks
- and more
A Wide Domain for AEEs ...

High Level Business Function

Product Development | Operations | Marketing & Sales | Finance | Human Resources

Enterprise Information System

SCM

Customer Relationship Management

Forecasting

Purchasing

Enterprise Resource Planning

Office Applications

Product Data Management

Logistics

Modeling, Simulation & Visualization

MES

CAPP

Supervisory Control

Machine Control

CAD

CAE

CAM

EDA
Notional Example – Robotic Arm

SYSTEM ENGINEERING
define hardware and software architectures and sub-system requirements

MOTION ANALYSIS
- Kinematic analysis
- Dynamic analysis

Mechanical Design
iteration

Structural Analysis
Identify stresses, deflections, modal responses, etc.

Mechanical Manuf’g
- Procure Components
- Fabricate Components
- Assemble
- Test

Servo Design
- Design control algorithms
- Simulate and evaluate

Firmware Design
- Real-time µP software
- FPGA configuration

Electronic Design
µP- and FPGA-based digital control system
- Schematic capture
- PWB layout
- Performance modeling & simulation

Electronic Manuf’g
- Procure Components
- Fabricate PWB
- Assemble PWB

Integration and Test
Notional Example – Robotic Arm

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Integration and Test

Requirements Mgmt Tool

CAE
Notional Example – Robotic Arm

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Integration and Test

Control Systems Tool

EDA Tools

Requirements Mg’t Tool

CAD

e-Catalogs

CAE

e-Catalogs

Requirements Mg’t Tool

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CAE

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Mechanical Design
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Integration and Test

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CAE

Control Systems Tool

CASE Tools

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Requirements Mgt Tool

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Requirements Mg’t Tool

CAE

CAE (FEA)

CASE Tools

EDA Tools

e-Catalogs

MRP

CAM

ATE

CAD

e-Catalogs

CAE

CASE Tools

EDA Tools

e-Catalogs

MRP

CAM

ATE

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Notional Example – Robotic Arm

**SYSTEM ENGINEERING**
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**MOTION ANALYSIS**
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**Notional Example – Robotic Arm**

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  - Iteration

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**Integration and Test**
- ATE

**Requirements Mg’t Tool**

**Control Systems Tool**

**CASE Tools**

**EDA Tools**

**e-Catalogs**

**CAE (FEA)**

**CAE**

**MRP**

**CRM**

**PDM**

**ERP**

**CAM**

**ATE**

**RMD**
Notional Example – Robotic Arm

SYSTEM ENGINEERING
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Requirements Management Tool

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Electronics Design
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  - PCB layout
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Electronic Manufacturing
- Procure Components
- Fabricate PCB
- Assemble PCB

Integration and Test
- ATE
The Problem: AEEs @ SMEs

SMEs need to adopt AEEs...
... to perform the more technical design work outsourced by the Primes
... to meet the communication and collaboration demands of the Primes
... to meet the cost and schedule pressures induced by intense global competition

AEEs are difficult for SMEs to adopt
- Technology challenges
- Skills Challenges
- Financial Challenges
One Approach

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Comprehensive AEE

A suite of fully interoperable, integrated tools operating upon a common database of information accessible to all relevant design and analysis tools.

- Vision for the future
- Not fully realized today.
- Some tool integration from major vendors
Intermediate AEE

A suite of interfaced and interoperable tools (e.g. CAD, CAE, CAM, PDM) sharing compatible data.
- Partially available today
- Standard interfaces (STEP)
- Some tool integration from major vendors
Basic AEE

A CAD system and compatible CAE systems
• Readily available today  • Within reach of SMEs
Operational Benefits of AEEs

Product Development and Production Time
- Provide accurate and rapid response to RFQs
- Minimize duplicated and repetitive work
- Reduce design iterations needed for successful design
- Maximize reuse of designs and design elements
- Improve interdisciplinary communication and collaboration

Cost in Product Development and Manufacturing
- Design Optimization
- Risk Reduction through Design Experiments
- Manufacturing Optimization through Simulation
Operational Benefits of AEEs

Product Quality

- Enhanced Depth of Performance Analysis
- Optimization of Final Design
- Improved Collaboration in Early Design Stages
- Expanded Reuse of Proven Designs
- Enhanced Methods of Quality Evaluation
External Benefits of AEEs

Coping with Global Enterprises and Markets
- Improved flexibility
- Faster response to market demands

Improved Communication with Customers & Suppliers
- Access to supplier e-Catalogs
- Accurate data exchange with suppliers
- Accurate data exchange with customer
- Improved capability for collaboration with customer
Barriers for SMEs

Smaller manufacturers are not embracing many of the latest, best software tools. WHY?

• Lack of awareness
• Financial & Business Issues
• Technology Issues
• Organizational / Cultural roadblocks
• Vendor Issues
Lack of Awareness

SMEs lack awareness of available COTS technologies and the potential benefits they can provide.

Challenges
- Lack of IT skills
- Unbiased consultants familiar with the domain and the technology are rare

Keys to Success
- Create a technology strategy
- Assign employees to study technologies
- Self-assessment tools
[Ref 4, Ref 5]
Financial / Business Issues

The risks & benefits must be evident for an SME to consider investing in software technology

Challenges
- Absence of Business Cases
- Identifying costs and benefits
- Competition with non-software investment options

Keys to Success
- Provide examples
- Identify costs and benefits for technologies [Ref 1, Ref 2]

Technology must be clearly tied to an SME’s business objectives for measurable impact

Challenges
- Absence of technology adoption planning
- SME focus on short term benefits

Keys to Success
- Integrate technology into business planning
- Educate owners/CEOs on the role of technology
Technology Issues

Technology management is not an SME CORE COMPETENCY

Challenges
• Legacy systems & data
• Resources for IT support

Keys to Success
• Attention to interoperability
• A selection PROCESS [Ref 3]
• A support plan

Incompatible technology demands from multiple customers

Challenges
• Multiple system compatibility

Keys to Success
• Attention to interoperability
• Translation products and services
Organizational / Cultural Issues

**Insufficient definition and understanding of the As-Is business processes is the standard among SMEs**

<table>
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<th>Challenges</th>
<th>Keys to Success</th>
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<td>• Tribal knowledge</td>
<td>• Document the As-Is process</td>
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<tr>
<td>• Pride in flexible processes</td>
<td>• Use appropriate level of detail</td>
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<td>• Culture of informal teamwork</td>
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SMEs believe they are too busy and do not have time to do effective technology planning activities

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<th>Challenges</th>
<th>Keys to Success</th>
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<td>• Small size of organization</td>
<td>• Highlight cost of not planning</td>
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<td>• Flat management structure</td>
<td>• Break up planning activities</td>
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<td>• Culture focus on short term benefits</td>
<td>• Constantly communicate benefits</td>
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Vendor Issues

Vendors do not target, and may specifically avoid, marketing to SMEs

Challenges
• focus on sales per sales call
• perception that SMEs require more support

Keys to Success
• Awareness: SMEs are a growth market
• Consider an ASP model

There is a training gap between COTS training providers and SMEs

Challenges
• Vendors provide general product training
• training needed to apply the product to their SME’s needs

Keys to Success
• Vendor consulting services
  - Bridge the training gap
  - Mentor to support risk management
Key Areas to Address - Education

... for SMEs
- AEE Concepts
- Benefits of AEEs
- Technology Adoption Processes
- Workforce Development

... for Tool Vendors
- Awareness / Appreciation of SME market niche

... for Tool Developers
- AEE Concepts
- Interoperability Standards
- SME needs and capabilities
References

1. S. Fenves, R. Sriram, Y. Choi, J. Elm, J. Robert
   *Advanced Engineering Environments for Small Manufacturing Enterprises: Volumes I and II*

2. J. Elm, J. Robert
   *Integration of Computer-Aided Design and Finite Element Analysis Tools in a Small Manufacturing Enterprise*

3. W. Anderson, L. Estrin
   *Advanced Software Technology Selection in Two Small Manufacturing Enterprises*

4. S. Fenves, J. Elm, J. Robert
   *Self Assessment Tool for Engineering Environments (SAT-EE)*

5. S. Fenves, J. Elm, J. Robert
   *Self Assessment Tool for Engineering Capabilities (SAT-ETC)*

References are available via:
http://www.sei.cmu.edu/tide/publications/abstracts.html
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