CHAPTER 21

NDEMC Midwest Pilot in the United States of America

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CONTENTS

21.1 INTRODUCTION

The National Digital Engineering and Manufacturing Consortium (NDEMC), a public–private partnership, was founded in 2010 by three Midwest university supercomputer centers, four FORTUNE100® manufacturers, the National Center for Manufacturing Sciences, and the U.S. Council on Competitiveness. John Deere, GE, Lockheed Martin, and P&G each invested $500,000 of cash and in-kind services, matched equally by the U.S. Economic Development Administration (EDA). Small and medium manufacturers (SMMs) were chosen by each original equipment manufacturer (OEM) to participate in advanced digital modeling and simulation at no cost. The pilot lasted approximately 30 months.

NDEMC STAKEHOLDERS

OEMs ($2 million)
Deere & Company
General Electric
Lockheed Martin
Procter & Gamble

Solution Partners
NCSA (National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign)
OSC (Ohio Supercomputer Center, The Ohio State University, Columbus, Indiana)
NCMS (National Center for Manufacturing Sciences, Ann Arbor, Michigan)
Purdue University, Indiana

Non-Profit Fiduciary
U.S. Council on Competitiveness

Federal Government ($2 million)
Economic Development Administration
White House (Office of Science and Technology Policy, Federal CTO)

State Governments
State of Ohio ($1 million)
State of Indiana ($150,000)

Other Signees
NSF (National Science Foundation)
NSF (National Science Foundation)
DOE (Department of Energy)
NIST (National Institute of Standards and Technology)
NASA (National Aeronautic and Space Administration)

Initially, two suppliers per OEM were chosen, whose advanced modeling and simulation capabilities ranged from none to modest. In each case, these companies were using two-dimensional (2D) geometry CAD (computer-aided design) packages, whereas some companies were using 3D modeling applications on desktop computers. None were using supercomputers. The difference between 2D and 3D can be described as the comparison between a traditional blueprint and a 3D rotating image of a part that fits in an assembly (as in the *Iron Man* movies).[1] Advanced simulations explore structures using finite-element analysis (FEA), computational fluid dynamics (CFD), thermal progression (such as molten steel as it cools), and other physical domains, either separately or together. The most advanced simulations, known as multiphysics simulations, analyze two or more physical domains simultaneously.

The initial scope for NDEMC was to concentrate on 3D simulation training that used well-known commercial off-the-shelf (COTS) codes.

Structures and fluids are the two fundamental engineering domains with a handful of commercial codes from independent software vendors (ISVs) that supercomputer centers as well as small manufacturers would be familiar with, such as ANSYS Mechanical, ANSYS Fluent, Simulia Abaqus, and CD-adapco's Star-CCM+. With permission from the ISVs, benchmarks and analyses were conducted on university supercomputers. Performance improvements were quickly achieved using more processing power than was available on desktop computers. Structural inputs were evaluated, specific physics was verified, and expert analyses were made of the simulation techniques.

21.2 NDEMC CASE 1: JOHN DEERE AND ADAMS THERMAL

One of John Deere's suppliers is Adams Thermal Systems, a charge air cooler (CAC, or radiator) manufacturer in South Dakota. John Deere's desire to engage Adams Thermal was due in large part to the impact the radiator has on the efficiency of (and emissions from) an internal combustion engine. As one can imagine, the radiator on a tractor is large, and design decisions impact the placement of hoses for fluid inputs and outputs, the speed of fluid transport, the angles of turns, widths of openings, density of cooling fins, placement of welds, and more. Better-informed initial design choices produce long-lasting parts and assemblies and more efficient fuel consumption.

Digital design of experiments, or experimental design, is the design of any information-gathering exercise where variation is present. Iterative designs will help an engineer optimize a design, and running multiples of these designs are aided significantly by supercomputing in two ways: (1) running on a larger number of processors and (2) running multiple simulations at the same time. The typical platform for digital design is a computer workstation with 4–8 cores with one or two CPUs (central processing units). The software licensing for these applications is typically charged by the core, which is the smallest unit of processing, and the licenses are often calculated based on annual use. These applications are powerful, and their licenses can easily cost 10 to 30 times more than a desktop computer.

Adams Thermal would run a single CFD simulation on the entire computer for 3 days. NCSA's first task was to take the same input file used on the workstation and run it on as many cores as possible on a supercomputer, using the identical CFD application. Immediate improvements were achieved with this effort, running efficiently up to 192 cores from the previous eight, reducing runtime from 3 days to 3 hours. In essence, the simulation easily ran on 24 computers instead of one. Success!

The 3-hour runtime created an opportunity for changes in workflow at the company, promising as many as 12 times as many runs in the original 3-day runtime. These extra runs would allow the designer to assess iterations of the initial design, or a suite of options rather than a single design.

Analyzing the costs for this computing is straightforward, as costs at NCSA and other supercomputer centers are typically quoted by the core-hour. Running on 192 cores for 3 hours converts to 576 core-hours, costing less than $125. Predicting the cost of the software licenses for 192 cores is not straightforward, as ISVs typically do not sell to companies that have access to supercomputers. This is changing, however, and the pricing models are beginning to take into consideration a sliding scale for core-hour pricing. Closer cooperation between supercomputer centers and ISVs is expected to provide promising performance increases for SMMs.

All companies must get product out the door on time, so engineering workflow is central to meeting customer design targets. As no manufacturer has unlimited time to explore optimal designs, trade-offs are introduced and must be assessed. The use of coarser models with less realism, which is typically what happens on a desktop, can increase the sheer number of iterations. Higher-fidelity models could be produced that would add more design realism, but they would take much longer to run on a desktop. Alternatively, a supercomputer could be used to add significantly more realism in a timeframe that would fit within the design workflow allotted.

Adams Thermal opted to pursue more realistic models, prompting the following issues:

1. Costs for computing and licensing would need to be quantified, and regular access to HPC resources assured for this to become a repeatable workflow.

2. The vision of more realism yet could be achieved by coupling the fluid and structural physics models. Adding thermal assessment and metal fatigue analysis, however, created an extremely complex

multiphysics challenge that was determined to be beyond the current capability of the software applications.

Unleashing a vision is a ton of fun, and the promise of unlimited compute power can do strange things to normal people. As Adams, Deere, and NCSA continued to analyze the complexity of the CAC, it became evident that the ultimate goal would be to simulate the entire assembly (Figure 21.1). Structural parts included the frame and the internal metallic fins. Fluid dynamics would analyze the flow of water throughout the assembly, thermal progression analysis would help find hot spots, and proper joint fatigue analysis would inform engineers in ways that would improve life of the assembly and reduce costs.

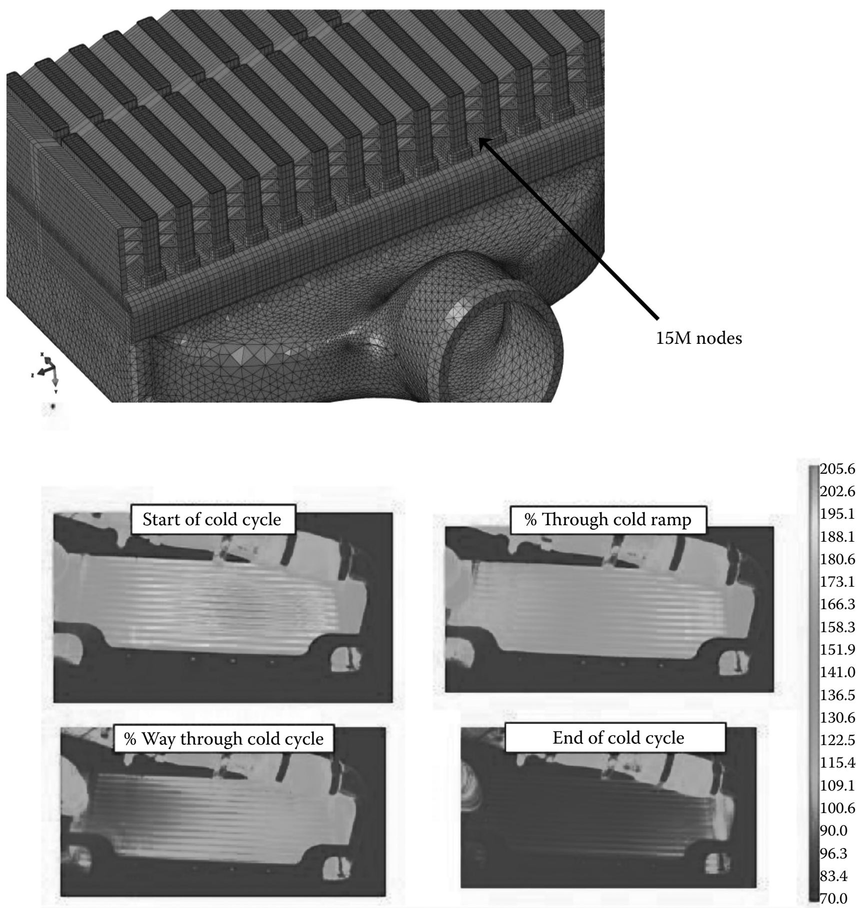

FIGURE 21.1 Multiphysics simulation of a charge air cooler.

The objective was to study the fatigue life of the CAC due to thermal stresses. A three-step sequential simulation was performed:

1. CFD of turbulent fluid flow through the CAC coupled with advective heat transfer (HT) provided thermal boundary conditions for structural analysis.
2. Structural analysis of the thermomechanical parts provides transient thermal stresses in the solid part during the thermal cycle for fatigue analysis.
3. Fatigue Model uses history of thermal stresses and estimates the cycle life at critical points.

Multiple physical analyses, or multiphysics, require the coupling of domain-specific codes to run together in time steps. Programmers must know enough about each code to link them to these time steps so they can be run across multiple CPUs simultaneously. Multiphysics is quite promising if a framework exists to link both fluid and structural codes. However, coupling domain codes from one ISV to the code of another is problematic without full cooperation from each ISV. ANSYS claims multiphysics between its own structural and fluids codes, and CD-adapco is in agreement to share with Simulia's Abaqus structural code.

Chapter 1 describes how Ford Motor Company used 20,000 structural elements for FEA designs in 1985. Today's highly advanced FEA designs will use 30 million elements. The Adams CAC model was estimated to require 100 million elements and a full man-month or two to develop such a sophisticated model. The complexity driven by this specific problem was extreme and not previously accomplished using commercial codes. NCSA and Deere's internal engineering team ultimately developed a reduced-order model and created a non-numerical method to add thermal values to the analysis, an effort beyond the scope of the NDEMC Midwest Pilot.

Lessons learned:

1. Funding for extreme physics-based modeling and simulation does not currently exist from science and engineering funding organizations.
2. One answer was received to the provocative question of what one would do with infinite compute power.

3. No one—absolutely no one—expected such an extreme engineering design challenge from a small company in South Dakota.
4. A recipe for repeatability is uncertain, but currently requires a reduced-order, less realistic model to meet cost and workflow demands.

21.3 NDEMC CASE STUDY 2: JOHN DEERE AND ROSENBOOM MACHINE AND TOOL

A family-owned John Deere supplier in Iowa designs and produces hydraulic cylinders (Figure 21.2) and machine parts for a variety of markets. Rosenboom engineers had no experience with 3D digital design simulation software, yet wanted to make more informed decisions about multiple design options within the typical single week allocated for bidding

FIGURE 21.2 A stack of hydraulic cylinders. (Photo credit: www.rosenboom.com).

for customer business. The initial strategy was to train the company engineers on CFD tools so they could more quickly and accurately analyze the behavior of hydraulic fluid in a cylinder.

NCSA hosted a 2-day training workshop in Champaign, Illinois, for all NDEMC participants on a wintry day in January 2012, and several Rosenboom engineers attended. Fundamental aspects of CFD were taught using ANSYS Fluent, and FEA simulation was taught using Simulia Abaqus. All participants accessed NCSA's industrial supercomputer, iForge, in real-time.

Rosenboom engineers were thrilled with what the new CFD tools could do for them, quickly proving their return on investment (ROI) of time by using CFD to reduce 6–10 potential cylinder designs to a single optimal design with a measurable reduction in uncertainty. Rosenboom increased export sales by $7 million and hired 150 new workers during the project.

Lessons learned:

1. The highest return on investment for training was using CFD.
2. Rosenboom engineers and management achieved unexpected benefits from learning FEA, as the ultimate goal of design was to reduce failures in the cylinder caps, which are welded to the cylinder body.
3. Student engineers with no previous experience with digital 3D design tools quickly became more productive.
4. The "obvious" choice to learn CFD did not achieve the ultimate goal of reducing fatigue on a welded cylinder cap. In ways very similar to Adams Thermal's desire to assess fatigue caused by thermal stresses, multiple physics analyses are required.
5. Understanding the engineering goals of the customer is paramount when introducing new tools.

21.4 NDEMC LESSONS FOR JOHN DEERE

Several OEM lessons should be noted from the NDEMC pilot:

1. The collaborative investment model between government and industry inspired behavior that would not have occurred by either side alone.
2. John Deere used the NDEMC project to survey its suppliers to determine the extent of advanced modeling and simulation being

conducted, asking for specific use of commercial, FEA, and CFD codes as determined by the initial NDEMC scope.

3. Deere had no previous insight into the extent of advanced modeling and simulation conducted in its supply chain.
4. Deere's existing partnership with NCSA's Private Sector Program provided a foundation of trust in technical capabilities that would last throughout the project and beyond.
5. Midway through the project, Deere management publicly stated that they had already achieved an ROI on their $500,000 cash and in-kind investment.
6. SMMs could not have achieved as much success as they did without hands-on involvement from Deere.
7. Support from Deere's CEO Sam Allen cleared the way for high attention within the company to this high-visibility project.

21.5 NDEMC CASE 3: GE, ESI, AND AN UNNAMED SUPPLIER

Success came in yet another unexpected manner with the GE-funded project. The chosen supplier manufactured wind turbine blades of significant length, and the project was to adopt 3D modeling of the entire turbine blade (Figure 21.3) rather than a fractional slice of the blade. ESI Group[2], founded in France in 1973, provided a CFD application, PAM-RTM, tuned for 2.5D on a workstation computer. GE's desire was to have its supplier adopt advanced 3D modeling and simulation. The supplier had no previous knowledge of 3D digital modeling.

The NDEMC funding agreement provided that no capital outlay would be required by the SMM other than in-kind time and attention. After training and engaging both the supplier and the ISV, the supplier opted not to move forward and ultimately withdrew from the NDEMC Midwest Pilot.

Failure often induces unintended consequences, and in this case it certainly did. The team's choice to move forward was as follows: improve the ESI code to full 3D capability or introduce another 3D application. Since the NDEMC modus operandi was to meet the customer on their terms, the team worked closely with the ESI software development team to improve code performance. The code had severe limitations in an HPC

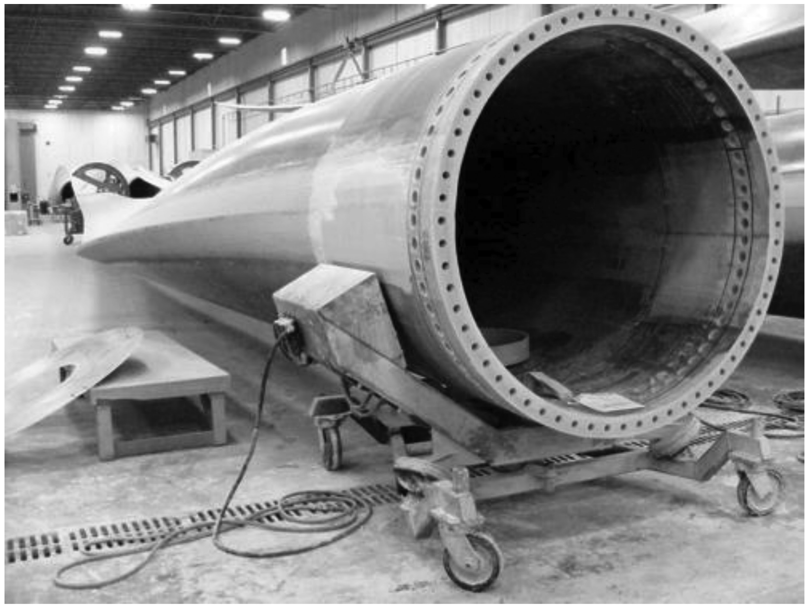

FIGURE 21.3 A completed wind turbine blade on the factory floor.

environment because it had no message-passing interface (MPI) capability to run outside a single node. The NCSA team provided code development expertise to the ESI team directly, ultimately helping them adopt scalable multinode capabilities. Multinode capability was essential to adding sufficient realism to jump from 2.5D to full 3D simulations.

Lessons learned:

1. All SMMs are not created equally, and should not be expected to equally adopt advanced tools.
2. Rapid advances in 3D modeling at OEMs will put immense pressure on SMMs to adopt these digital tools. SMMs that choose to adopt will win. SMMs that choose the path of inertia will lose, because OEMs will not settle for yesterday's performance in today's competitive marketplace.
3. Not all engineers appreciate the benefits of HPC, yet once exposed to systems and expertise, most engineers can be expected to become rapid adopters.
4. OEMs have an inherent conflict of interest if they attempt to do too much for a single supplier.

5. Innovation is often a bottom-up process, but OEM knowledge and expertise is invaluable to all parties.
6. ISVs can benefit immensely from expert development teams at supercomputer centers.
7. Business models and cultural inertia are barriers to changing behavior and priorities.
8. ESI can become the hero in its PAM-RTM application niche if it collaborates with HPC centers and aggressively competes against non-MPI application vendors.

21.6 NDEMC CASE 4: JECO PLASTIC PRODUCTS, LLC

Jeco Plastics[3] is a small, custom-mold manufacturer of large, complex, high-tolerance products in Indianapolis, Indiana. The project chosen for NDEMC was to predict the performance of a plastic pallet (Figure 21.4) that was customized for Volkswagen, a large automotive OEM in Germany. The OEM was requesting last-minute design changes to an existing product. Company engineers had no previous experience with advanced digital modeling and simulation and were relying on tedious trial-and-error physical design and testing. High-ranking executives at the OEM suggested that Jeco adopt advanced digital tools.

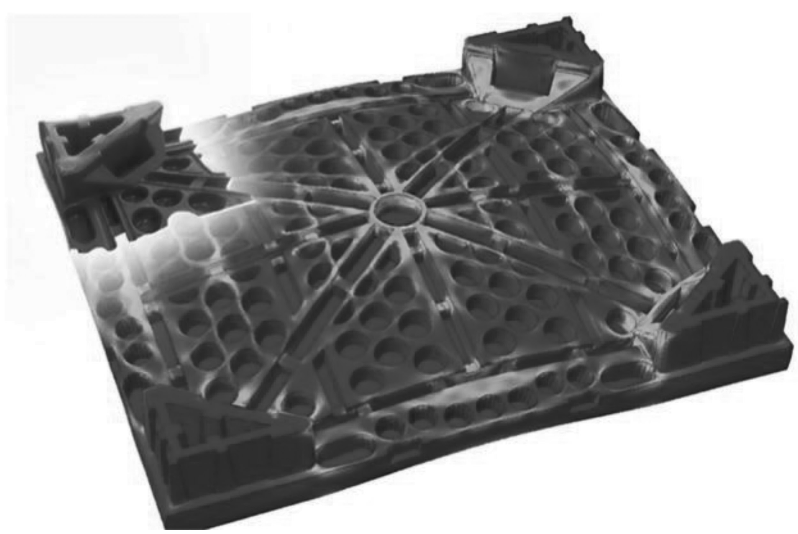

FIGURE 21.4 3D virtual image of a Jeco plastic pallet.

The technical challenge was to simulate complex, high-tolerance designs in inhomogeneous anisotropic materials. Anisotropy is a material's directional dependence of a physical property, such as the strength of wood when splitting along or against the grain. Jeco understood that the relatively small cosmetic alteration required by their client could potentially affect critical specifications for deflection, yet to secure the rather large contract they had to rapidly analyze the effect before making expensive, irreversible tool changes in the production process. NDEMC facilitated Jeco's access to expert staff at Purdue University and Ohio Supercomputer Center, who recommended the use of Abaqus[4] for FEA.

With the expertise and access to HPC-enabled advanced modeling and simulation, Jeco completed the technical analysis in time, securing a multi-year contract with annual orders of $2.5 million for the next 5–10 years. Fifteen jobs were added at the company following an initial capital investment of $500,000.

Lessons learned:

1. Jeco's demonstrated experience with advanced modeling and simulation during the NDEMC Midwest Pilot was instrumental in helping the company secure additional projects with aerospace and automotive customers.
2. Jeco subsequently received a lucrative order from NASA based on its new ability to design and manufacture products in layered anisotropic materials with continuous internal fiber reinforcement.
3. Advanced modeling and simulation has become a vital resource in Jeco's product development process.

21.7 NDEMC OVERALL LESSONS LEARNED

1. Train early and often.
2. Expect big things in small packages.
3. Do engage the OEM whenever possible.
4. Do invite the ISVs to engage technically.
5. Do treat the ISVs generously, as they will become either the bottleneck or the hero.

6. Do not immediately suggest changes in software applications to a customer, as there is neither time nor appetite to learn new tools in the initial engagements. Once a customer climbs the learning curve, more advanced software may be needed and desired.
7. Technical consulting staff must speak the languages of physics and engineering, not just HPC and CPUs.
8. The learning curve is steep when climbing alone. Always get professional help.
9. Companies need a trusted third-party advocate to guide them through the maze of software applications.
10. It is incredibly easy to get out of scope. NDEMC had wide measures of freedom in its Midwest Pilot, but care must be taken to properly fund more complex projects in a continuing organization.
11. More OEM/SMM collaboration is needed. The manufacturing supply chain cannot survive without it.
12. OEM technical leaders need to engage with suppliers. Procurement processes will not change without clear technical insight into supplier capabilities.
13. OEMs are not asking suppliers about their digital capabilities, but they should.
14. Development processes specific to suppliers' products drive the need for customized engagements, which are difficult to template and make repeatable.
15. The gap between OEM and SMM technical capability is widening. Some suppliers will be left behind, but OEMs need to engage with suppliers in new ways or they will risk losing all suppliers in certain niches.
16. Private sector investment is crucial to success. Without it, a government struggles to change behavior.
17. A "build-it-and-they-will-come" model will not work. Outreach needs to be on SMM terms with "boots on the ground."
18. Access to commercially viable supercomputing is crucial, as detailed proofs of concept are needed for rapid adoption.

19. The demand for subsidized services is endless. SMMs cannot afford to adopt advanced MS&A on their own, but with proper assessment of ROI, changes in behavior and SMM investment can be achieved. A key step in adoption is to reduce the uncertainty of the investment in digital tools, computing, and training.
20. Fundamental changes in costs for physical prototyping are required to adequately fund new digital tools and processes. If physical costs are 70% or 80% of R&D, they need to flip to 30% or 20% to make room for digital adoption. Alternatively, reductions in physical prototyping can conceivably fund investments in digital processes.
21. Strategic decisions must be made about subsidies to make SMM adoption of digital tools a lifestyle rather than a stunt.
22. Government-funded pilot programs are not designed to last forever.
23. Governance in a public–private partnership matters. Board members were industrial investors and the fiduciary U.S. Council on Competitiveness. Not represented on the board was any member of government, yet the EDA was a 50% investor. This was a mistake.
24. While all education and training may be local, collaboration is required, as not all HPC centers have expertise in advanced CAE modeling and simulation. E-learning is promising and must be attempted.
25. HPC center competition is unhealthy, because the real competition is not between machine providers. Expertise matters and there is not enough time and money to train all people equally.
26. OSC, Purdue, and NCSA learned to collaborate. Others can do so, too.
27. HPC centers must have the expertise and ability to manage commercial licenses; without it, all industrial engagement with SMMs will be "information only."

21.8 NDEMC OUTCOMES

The NDEMC team accomplished the following throughout the course of the project:[5]

1. Twenty SMMs were involved on more than a dozen projects.
2. Case studies were created for 10 of the demonstration projects.

3. Eight educational training videos were produced.
4. Several custom apps were created to simplify use of advanced modeling and simulation.
5. Based on workflow contributed by P&G, one app was specifically created for the simulation of fluid flows through a manifold. The Manifold Flow Predictor (MFP) accepts a CAD file and adds OpenFOAM CFD analysis and ParaView visualization. The MFP is hosted at Purdue University's ManufacturingHUB.org.
6. SMMs generated new business in excess of $25 million.
7. Related capital investment of $600,000 led to the creation of 160 new jobs.

ENDNOTES

1. http://www.youtube.com/watch?v=MqRVIEEp_AM.
2. https://www.esi-group.com/company/.
3. Council on Competitiveness Case Study, NDEMC Helps Jeco to Exceed Growth and Financial Expectations, ©2012.
4. Abaqus is owned by Simulia, a division of Dassault Systèmes in France.
5. NDEMC Final Report, August 29, 2013, www.ndemc.org.