SMART PROCESS MANUFACTURING WORKSHOP REPORT

FROM

APRIL 21-22, 2008
NSF ROADMAP DEVELOPMENT WORKSHOP

VERSION 1.1
16 MAY 2008

IMTI-08023

FOREWORD

This document was produced by the Integrated Manufacturing Technology Initiative (IMTI, Inc.) in support of the Smart Process Manufacturing Engineering Virtual Organization (SPM-EVO).

The objective of this report is to support communication of work performed to advance Smart Process Manufacturing.

Primary input for this report was gathered at a workshop conducted April 21 and 22, 2008 at the NSF headquarters in Washington, DC. The workshop was sponsored by the National Science Foundation and the Smart Process Manufacturing Engineering Virtual Organization (SPM-EVO).

CONTRIBUTORS

Miguel Bagajewicz, University of Oklahoma
Wayne Bequette, Rensselaer Polytechnic Institute
Larry Biegler, Carnegie Mellon University
Maria Burka, NSF
Panagiotis Christofides, UCLA
Peter Cummings, Vanderbilt University
Jennifer Curtis, University of Florida
Jim Davis, UCLA
Yiannis Dimitratos, DuPont
Mario Richard Eden, Auburn University
Tom Edgar, University of Texas
Mike Elsass, Ohio State University
Larry Genskow, Proctor & Gamble
Christos Georgakis, Tufts University
Jerry Gipson, Dow Chemical Company
Ignacio Grossmann, Carnegie Mellon University
Juergen Hahn, Texas A & M University
Bruce Hamilton, NSF
IIro Harjunkoski, ABB AG
Peggy Hewitt, Honeywell
Yinlun Huang, Wayne State University
Son Huynh, IBM
Sara Jordan, IMTI
Jayant Kalagnanam, IBM
David Kofke, State University of New York at Buffalo
Paul McLaughlin, Honeywell
Milo Meixell, Aspen Tech
Aniruddha Mukhopadhyay, ANSYS, Inc.
Lakshman Natarajan, British Petroleum
Charlie Neal, IMTI
Richard Neal, IMTI
Jerry O’Brien, PDC Corporation
Jim Porter, DuPont
Rex Reklaitis, Purdue University
Mike Sarli, Exxon Mobil Research & Engineering
Pete Sharpe, Emerson Process Management
Jeff Siirola, Eastman Chemical Company
Bruce Strupp, CH2M Hill
Jorge Vanegas, Texas A& M University
Jin Wang, Auburn University
Camille Yousfi, Shell

CONTENTS

1.0 INTRODUCTION

1.1 BACKGROUND

On April 21-22, 2008, a workshop about smart process manufacturing was conducted at the NSF headquarters in Washington, DC. The purpose of the workshop was to bring together experts in the field and integrate their best thoughts into a cohesive plan to address the identified issues.

A diverse group of companies, government agencies, and academic organizations were represented by 41 participants to begin the process of developing a roadmap for smart process manufacturing. The workshop was sponsored by the National Science Foundation and the Smart Process Manufacturing Engineering Virtual Organization (SPM-EVO).

The two-day workshop focused on critical research needs for achieving smart process manufacturing with zero incidents and zero emissions. The session encompassed applications in chemical, biological, pharmaceuticals, and materials industries, and involved energy, environmental, and safety perspectives in the process context.

Workshop attendees participated in a combination of plenary and small-group sessions. This "summit" of experts, practitioners, users, and visionaries from the process manufacturing community took advantage of this unique opportunity to help chart a future that will exploit the potential technological direction and deliver breakthrough advances for this critical area.

This document accomplishes a significant early-step in the process of developing a strategic roadmap for the smart process manufacturing area. The subsequent roadmap and supporting information will be managed as a living document for use by the SPM-EVO to initiate actions that will mature the roadmap and greatly accelerate the advancement of smart process manufacturing.

1.2 ORIGINS AND PRELIMINARY WORK

With an awareness of activities of other industries and sectors and of the need to come together as an industry to solve technical problems, a foundational workshop related to process manufacturing was conducted in September 2006 at NSF.

The title of the workshop was "Cyberinfrastructure in Chemical and Biological Process Systems: Impact and Directions."[1] The workshop included representatives from chemical and biological processes, systems biology, pharmaceuticals, and metabolic engineering and addressed energy, environmental, nano- and bioscience perspectives in the process context. The theme areas were defined by industries, applications, processes, and systems primarily characterized by chemical and biological transformations and material, energy, and information flows.[2]

[1] The report from this workshop is available at www.oit.ucla.edu/nsfci/default.htm.

[2] This text is adapted from the Engineering Virtual Organization proposal submitted to NSF under the Cyber-Enabled Discovery and Innovation program.

The workshop identified smart process manufacturing as a grand-challenge problem that stands out in terms of priority and economic impact, one that should be pursued in an organized manner by the chemical and biochemical process systems engineering community with the intent of building a national agenda and the technology roadmap required to address critical research needs. The workshop attendees concluded that development of a roadmap would produce the added benefit of a set of foundational tools that will be useful across the industry for many applications. Subsequent discussions confirmed that the goals of this cross-industry initiative cannot be achieved through company-by-company efforts, but require a collaborative entity working toward the larger purpose, with appropriate attention paid to questions of how to use proprietary and non-proprietary information within companies and across the industry.

With this foundation, a proposal was submitted to NSF for the creation of an Engineering Virtual Organization (EVO) to develop the roadmap and move ahead to deployment. The proposal was successful, and this present activity is on the critical path for developing the roadmap and achieving that synergistic environment in which process industry needs will be illuminated and the needed focus will be brought to bear for solutions.

As part of the EVO structure, a steering committee has been established. That steering committee includes:

- Jim Davis, Principal Investigator (PI) – UCLA
- Tom Edgar (co-PI) – University of Texas, Austin
- Jay Boisseau – Texas Advanced Computing Center
- Jerry Gipson – Dow Chemical Corporation
- Ignacio Grossmann – Carnegie Mellon University
- Peggy Hewitt – Honeywell Process Solutions
- Ric Jackson – FIATECH
- Jim Porter – DuPont
- Rex Reklaitis – Purdue University
- Allan Snavely – San Diego Supercomputer Center
- Ray Topping/Bruce Strupp – CH2M Hill
- Jorge Vanegas – Texas A & M University

A subgroup of this committee has been established as the Technical Steering Team. This Board provides the leadership for development of the Smart Manufacturing Process roadmap.

Meeting of the Technical Steering Team

On March 25, 2008, the Smart Process Manufacturing Technical Steering Team met in Dallas, Texas to build an initial, high-level view of smart process manufacturing and provide a jump-start to the upcoming roadmapping process and workshop. This meeting focused only at the top level of the functional model. The results of the meeting were included in a pre-read package as baseline preparatory materials for the April 21-22 workshop.

The Functional Model

The roadmapping process begins with the creation of a functional model for the subject area. The model guides the data collection in the workshop, provides the structure for the roadmap, and, assuming deployment, serves as a work breakdown structure in implementation. In Figure 1, the three major categories under smart process manufacturing (the X.0 level) are referred to as the "pillars," and the topics under the pillars (the X.X level) are referred to as "foundational elements."

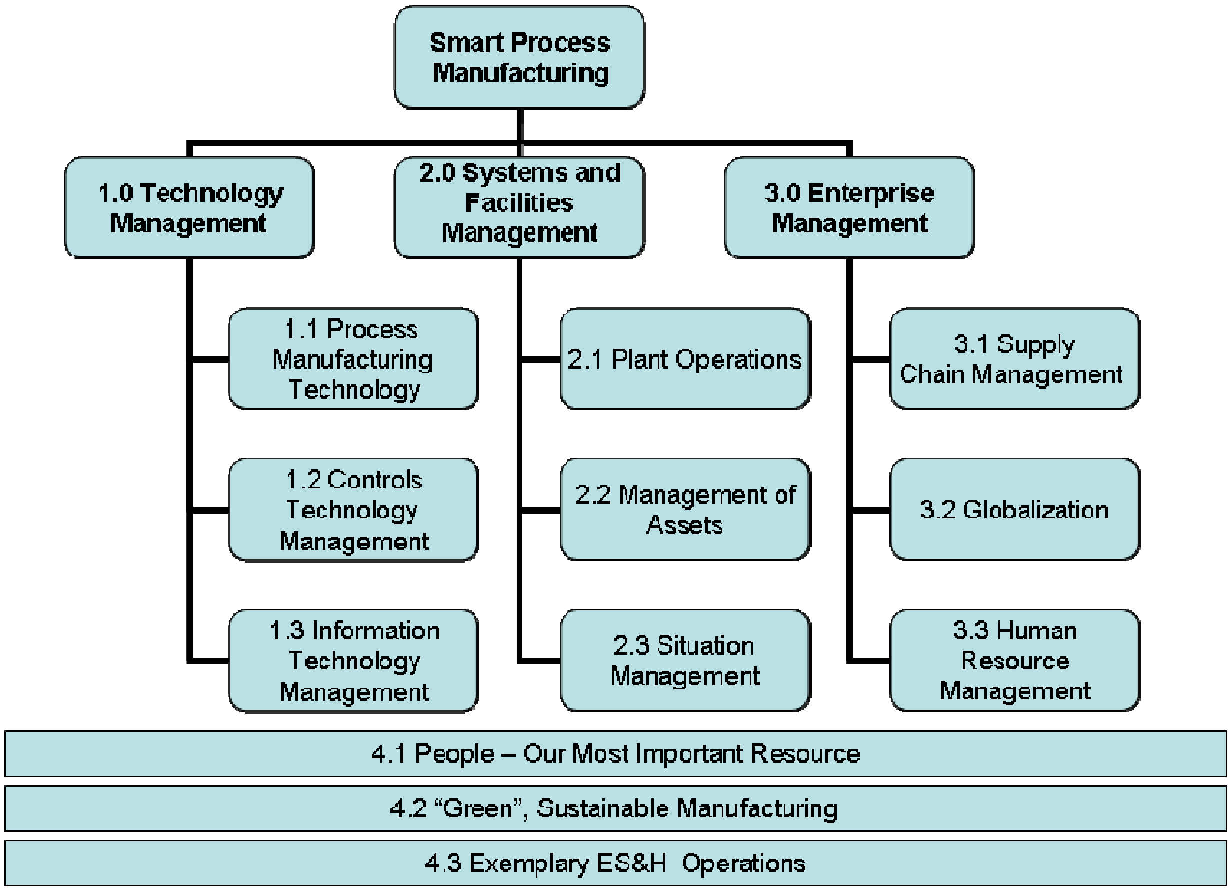


Figure 1. The Smart Process Manufacturing functional model provides a hierarchical, logical framework for analysis of technology research and development requirements.

As stated above, the functional model served as a guide for the workshop. Additionally, in preparation for the workshop, the Technical Steering Team developed an overarching description of smart process manufacturing which included the three pillars and cross-cutting topics. This descriptive overview is presented in the following section and served as a high-level starting point for the more detailed assessment that was performed at the workshop. The detailed workshop results are included in the subsequent pillar sections of this document.

1.3 Smart Process Manufacturing Overview

Smart process manufacturing is the realization of a continuous or batch manufacturing environment wherein all critical elements are maintained within acceptable operating conditions and the product is qualified for sale and delivery based on the automatic adaptation and assurance of in-control operation. In addition to product quality, smart process manufacturing embraces all operational aspects. Smart process manufacturing is the enterprise-wide application of "smart" technologies, tools, and systems coupled with knowledge-enabled personnel to plan, design, build, operate, maintain, and manage process manufacturing facilities in full concert with the business and manufacturing missions of the enterprise.

Smart process manufacturing refers to a design and operational paradigm involving the integration of measurement and actuation, ES&H protection, regulatory control, real-time optimization and monitoring, and planning and scheduling. This integrated processes approach provides the basis for a strong predictive and preventive mode of operation with a much swifter incident-response capability.

A smart process manufacturing environment drives towards zero emissions and zero incidents through proactive, predictive enterprise optimization and management. The smart process manufacturing enterprise ensures safe and health-conscious operations with full recognition of people as the most important resource for success. As a good steward of the environment, the enterprise implements technologies and practices to achieve sustainability, zero emissions, and zero incidents. Incorporating zero emissions into the smart manufacturing paradigm recognizes that energy usage, energy production, and environmental impact are tightly linked in volume manufacturing.

"Management" is in the title of all three pillars of smart process manufacturing. This does not mean maintaining status quo in a stable manufacturing enterprise; rather, it embraces proactive integration, optimization, planning, and improvement of all processes.

For the purposes of the workshop, process manufacturing is defined as the conversion of raw materials to product via continuous and/or batch chemical and/or biological processes. The workshop addressed both continuous and batch manufacturing and included, for example, web/film/sheet processes, but not discrete part manufacturing. The scope also included packaging of batch products, although this is a borderline topic. Most companies are very client-focused with respect to how a customer perceives the package, so packaging is a very significant aspect of the product. Packaging also impacts product quality, safety, and exposure to environment.

What is meant by "Smart":

- Smart process manufacturing systems are capable of intelligent actions and responses. They have the ability to apply learning processes to determine appropriate action, and to implement that intelligent action (e.g., adaptive, predictive, proactive).
- A smart manufacturing system can adapt to new situations or perturbations (i.e., abnormal situations). By evaluating the present circumstances and applying captured knowledge, the systems can determine the best response to any change in performance conditions.
- Any pertinent information is available, accessible, and understandable to the various parties or functions that need the information, and is timely and appropriate – related to the system performance at the moment. The needed information is available when it is needed, where it is needed, and in the form in which it is most useful.
- Smart manufacturing systems are proactive. They incorporate real-time data sensing and proactive response to eliminate failure before it happens.
- In a smart manufacturing environment, assets are integrated and self-aware (via sensors) of their state. Assets may be many things: plant, equipment, knowledge, models, data properties.

- Field devices have intelligent processing capability with the sensors needed for self-awareness. They recognize their condition and publish that information so they or other devices can take appropriate action.
- "Smart materials" are those that respond in some desired way to environmental stimuli (light, temperature, etc.).
- Human resources (people) are knowledgeable, well trained, empowered, connected (via cyber tools), and able to adapt/improve the system's performance.
- Smart manufacturing systems are sustainable. Sustainable manufacturing includes reuse, with a life-cycle view of products and processes. A minimum environmental footprint (energy, water, emissions) is a high-priority goal of a smart manufacturing environment.

In light of the fact that this activity is associated with the Cyber-Enabled Discovery and Innovation program, emphasis should be placed on the importance of cyber-based smart manufacturing solutions. The following are attributes of a cyber-enabled environment:

- **Multi-scale dynamic modeling and simulation** based on sophisticated understanding and practical development at the level of the atom/molecule and the cell, but applied at the macro/global level of a company, a region, a state, or a country.
- **Large-scale optimization** to address large-scale problems at the strategic, tactical, and operational levels, specifically when addressing product pipeline management decision-making, detailed optimizations of process models, sensor networks, and optimization of micro-scale models such as molecular designs.
- **Data interoperability**, the ability to manage and communicate electronic product and project data between collaborating groups or companies and within individual companies' design, construction, maintenance, and business process systems.
- **Sensor networks** in huge numbers networked throughout the enterprise, serving as the information supply workhorses for these industries, supporting data communications, automated control systems, long and short term planning, predictive modeling, optimization, environment, health and safety management, etc.
- **Scalable requirements-driven security** at all levels, enabling protection (without undue impairment of functionality) from the vulnerabilities inherent in using powerful, commercial off-the-shelf software technology throughout the enterprise.

1.3.1 Technology Management

Technology Management addresses the determination of all the technological resources required to sustain, protect, and improve operations of the manufacturing enterprise. Typically, many types of technology are involved, and they act as enablers for both local and cross-enterprise/global issues: specialized processes and systems, tools, control systems, modeling capabilities, and the people whose knowledge and practical expertise make the processing successful. Even the current and archived data streams from production sensors are a resource that can yield insights and competitive production improvements.

1.3.2 Systems and Facilities Management

Systems and Facilities Management provides the oversight and assurance of readiness of the plant assets to execute all needed functions within the defined operating envelope. It includes the non-integrated smaller facilities; the larger, highly integrated facilities; and the neighboring, symbiotic-relationship facilities that share input/output streams. The topic includes maintenance and reliability and takes a local perspective, not including the supply network and globalization.

1.3.3 Enterprise Management

Enterprise Management takes an integrated view of all enterprise activities, including the integration of various functions within and across organizational boundaries. Hence, the span includes enterprise resource management within an organization and the management of the extended enterprise including the supply network, global relationships, etc. The perspective includes multiple plants working together, interaction between companies, and the integration and optimization of processing and business functions. Further, enterprise management includes business and strategic planning and positioning for corporate success.

1.4 CROSS-CUTTING TOPICS

The pillars define one view of the major functional components of a smart process manufacturing environment. However, many important aspects of the smart process environment cut across all functional areas and must always be at the fore of our thought process. Three of those areas are called out in the functional model and highlighted in this document.

1.4.1 People: Our Most Important Resource

No matter how automated and "smart" a process manufacturing plant is, highly trained personnel are still the most important ingredient. Although not purely "knowledge workers," the factory workers who operate machinery, monitor processes, and resolve abnormal situations can surely be considered knowledge-augmented workers. For smart-plant operations, tedious and repetitive decisions will be automated to eliminate mind-numbing routine and allow the knowledge-augmented worker more time to do what people do best: think. Experienced workers may notice some detail or trend in the plant's operation that triggers a process improvement or alerts them to a potential future problem. More serious situations may arise when the sensor network detects an unrecognized abnormal situation and no automated solution is available. In this case, knowledgeable workers can avoid catastrophes when they are empowered to make the right decision, at the right time, in the right context, and act upon it.

Creation of this skilled and trusted workforce requires a strategic commitment to education and training, and changing the mindset and culture of some companies. The workers must be flexible, skilled people who have computer literacy and are capable of learning and performing new operations based on ready access to information. They must understand the processes of the plant and the role those processes play in achieving the goals of the business, and (much like airline pilots) must have regular training on recognizing and mitigating potential unforeseen situations or abnormal events.

A significant aspect of valuing knowledgeable workers is the capture and reuse of their knowledge and experience, both to train new workers and to ensure access to the best available advice to support processes and events in their absence. Use of advanced information technology and web-based training and knowledge delivery will enhance worker job skills and performance, and thus will improve the overall plant's performance as well.

1.4.2 "Green" Sustainable Manufacturing

A key benefit of having a smart process manufacturing facility is that environmentally sound practices become automatic; they are part of the business drivers that guide all operations. The benefits of improved environmental performance on manufacturing operations can extend beyond improving the quality of the environment.

Potential benefits include cost savings resulting from more efficient material use, reduced energy costs, reduced product development time, improved workplace safety, and simplified compliance with international environmental regulations. Reductions in energy costs through recycling materials such as steel, glass, and aluminum can be 30 to 40 percent of the costs of raw material extraction and processing. It pays off repeatedly to reduce waste materials, because there are costs when the excess raw materials are purchased, second in processing costs when they are converted to waste, and finally as disposal costs.

Energy usage and production go hand-in-hand in process manufacturing. Smart manufacturing addresses the need to minimize energy use while also providing tools for energy production, a process that is often co-located with the plant. As conventional oil and gas supplies diminish, there is strong incentive to find cost-competitive new technologies that comply with increasing environmental regulations on emissions of sulfur, nitrogen, particulates, and carbon dioxide. Sustainable energy solutions are necessary to achieve the goal of zero emissions, which will in turn cause significant changes in how plants are designed and operated. Development and application of new process systems engineering (PSE) tools is crucial to making such a transition.

1.4.3 Exemplary ES&H Operations

In traditional manufacturing facilities driven by process efficiency, ES&H performance is a consequence determined after the fact. However, when moving beyond ES&H regulatory adherence as a prominent business driver to "zero-incident" operations, the driving goal is to have no negative impact on personnel, surrounding communities, or the environment in general. Smart plants proactively prevent environmental, health, and safety problems while they at the same time seize opportunities to optimize operational and financial performance. The ubiquitous sensors that enable smart manufacturing are increasingly multipurpose – while they are monitoring process accuracy, they are also monitoring environmental conditions, and any aberrations are immediately noted and mitigated.

Just as is the case for "green" manufacturing above, the same points can be made concerning healthy and safe operations. A smart process manufacturing facility will automatically be a safe and healthy operation, because safety becomes part of the business drivers that guide operations. Although "Safety is Job One" has long been a prominent slogan in many plants, in the smart manufacturing facility aiming at zero-incident operations, the use of smart sensors and tight process specifications will make unsafe operations virtually impossible.

Smart plants will quickly, efficiently and safely deal with accidental or deliberate faults, taking advantage of the existing and developing cyber-infrastructure capabilities to design and implement advanced fault-tolerant control structures. Further, the use of personal location devices will increase the safety of personnel by preventing the next step of a procedure from starting if there are people in a dangerous area who should not be there, or if key personnel are not at their required stations. Improved workplace safety is a key benefit from smart manufacturing.

1.5 Methodology

The objective of the Smart Process Manufacturing workshop was to provide much-needed focused collaboration through facilitated assessment and creation of the base foundation for a roadmap.

This document is a key step in the roadmap development process. The IMTI Roadmapping methodology was customized for this workshop to generate, capture, and provides the following content for this document:

1. A **Current State Assessment** for the three pillars –Technology Management, Systems and Facilities Management, and Enterprise Management – identifying Technical & Intellectual Barriers and Deficiencies, State of Practice, and Best Practices and Emerging Research

2. A Future State **Vision** for each pillar, articulating high-level goals and objectives for research and development (R&D) focus.

3. A framework of identified and prioritized **Issues and Solutions** within each pillar.

4. A full review and prioritization by the full compliment of workshop participants of **Key Solutions** to be pursued across the scope of Smart Process Manufacturing.

1.6 KEY SOLUTIONS - A FRAMEWORK FOR ACTION AND COLLABORATION

Table 1 is a listing of 31 key solutions identified by the workshop pillar teams. The solutions are listed by priority-for-action rank (based on voting by the workshop participants). Additional solutions/issues are documented in the pillar sections of this report.

The table "code" key is based on the pillar elements as follows:

Pillar 1 - Technology Management

- PM: Process Manufacturing Technology
- CT: Controls Technology Management
- IT: Information Technology Management

Pillar 2 - Systems and Facilities Management

- PO: Plant Operations
- MA: Management of Assets
- SM: Situation Management

Pillar 3 - Enterprise Management

- SC: Supply Chain Management
- GL: Globalization
- HR: Human Resource Management

Table 1 - Key Solutions

Rank	Key Solution	Issue Needing Resolution
1	**Solution MA-5-2:** Provide real-time, point of use, training using emerging technologies	**Issue MA-5:** Lack of adequate training of the workforce to operate in a model-rich environment
2	**Solution PM-4-2:** Develop theories and algorithms that enable the rapid evaluation of thermophysical properties from a molecular model in a way that exploits emerging microprocessor technologies.	**Issue PM-4:** Need to develop models and algorithms to enable the molecularly informed design and control in a way that exploits emerging computer technologies. Need smart data collection and processing.
3	**Solution PM-3-1:** Develop tools that rate the fault-tolerance of an early process design. Make pervasive use of process design methodologies that incorporate dynamic simulation to minimize and isolate faults and evaluate process operability on a real-world scale.	**Issue PM-3:** Need to design plant processes and instrumentation for fault-tolerant behavior and use bias-free data.

Rank	Key Solution	Issue Needing Resolution
4	**Solution SM-1-1:** Provide technology (models, sensors, wireless, network architecture, security) that enables assets to self diagnose, publish state, self heal, or initiate a proper safe response.	**Issue SM-1:** Lack of intuitive technology-based tools to prevent situations and prepare the plant (people and assets) for proper response.
5	**Solution CT-2-3:** Develop associated actuator and sensor instrumentation networks to accomplish fault tolerant control, that is compatible with other functions such as quality control, production accounting, online optimization, etc.	**Issue CT-2:** Require methods and algorithms that allow plants to robustly operate and take corrective actions to abnormal situations using more detailed process models and appropriate level of measurements.
6	**Solution PM-2-1:** Charter an independent group of academic and industry participants to create a universal set of metrics for evaluating the economic impact of process robustness, flexibility (ability for the process to handle multiple feedstocks), and fault-tolerance.	**Issue PM-2:** Design must reconcile multiple objectives and not focus solely on cost
7	**Solution IT-3-2:** Develop a baseline IT format that optimizes and integrates the data flow between different systems and platforms, and create incentives to accomplish this mission	**Issue IT-3:** Difficulty of integrating data between different systems and sources.
8	**Solution SC-3-1and SC4-1 (combined):** *Investigate how structured uncertainty (disruption) and parametric uncertainty can be treated to address KPI's (e.g., profit, sustainability, carbon footprint); and *Model energy use in supply chain and evaluate the carbon footprint	**Issue SC-3 and SC-4 (combined):** *Need to be able to assess and model uncertainty in the entire supply chain (demand/supply disruption) and manage associated risk for any set of KPIs (key performance indicators); and *Integrate the energy use associated with material flow in supply chain management, and evaluate the Carbon footprint, reuse (for zero emission), life cycle/span of the molecule (cradle to cradle)
9	**Solution PO-4-1:** Implement a holistic modeling approach leading to evolution of consistent hierarchical approach for scope and fidelity for targeted optimization functions (control, RTO, scheduling) with methods to validate model accuracy and its limitations.	**Issue PO-4:** Modeling: Models need scope, accuracy, and consistency to achieve total value

Rank	Key Solution	Issue Needing Resolution
10	**Solution SC-1-1:** Develop large-scale information retrieval techniques for rationalizing unstructured data and performing feature extraction in SC databases ...AND... SC-1-2 Use self-learning and adaptive techniques to evolve standards (meta models and/or semantic models) and to map process components to meta/semantic models	**Issue SC-1:** There is a gap between IT infrastructure and math models due to lack of standardization and different terminology in SC. There is a need to know how to reconcile different names, how to automate the mapping different language, how to merge different data base/structure automatically (many are manually currently)
11	**Solution PO-3-1 & PO-3-2 (combined):** Develop algorithms for large-scale hybrid (discrete and continuous) optimization, in particular take advantage of parallel computation/multi-core processors	**Issue PO-3:** Computational: Models of processes and operations grow with advancement in demand and capability. Computational limitations (hardware, algorithms, model formulation) come into play.
12	**Solution MA-2-1:** Develop systematic methods for developing data model (plant semantic reference data models) to support business processes related to asset lifecycle management decisions	**Issue MA-2:** Difficulty in collecting the right, validated data that supports the development of models and supports decision processing
13	**Solution HR-1-1:** Apply broader implementation of knowledge capture processes and practices.	**Issue HR-1:** Graying workforce and technical knowledge: loss of experience and accumulated knowledge and lack of development of next generation.
14	**Solution MA-3-2:** Develop knowledge decision support systems for lifecycle asset management and collaborative decision-making that includes risk and uncertainty analysis.	**Issue MA-3:** Lack of predictive, coherent, decision making for maintaining and assuring reliability of assets and their operating environment including risk management
15	**Solution MA-4-1:** Provide a knowledge management solution that allows operators, engineers, - all stakeholders to collaboratively enrich the knowledge base and extract value from the collective knowledge set	**Issue SM-2 & MA-4 (combined):** *The loss of process operations knowledge/skills works against the ability to diagnose and respond; and *The lack of a systematic approach to capture the experience and knowledge of the workforce in a usable form
16	**Solution SM-1-2:** Provide plant wide visualization of critical information. The system will pull process variable, do correlation and pattern recognition, and publish output.	**Issue SM-1:** Lack of intuitive technology-based tools to prevent situations and prepare the plant (people and assets) for proper response.
17	**Solution CT-2-1:** Develop methods for fault detection and isolation, accounting explicitly for controller design as well as fault tolerant control.	**Issue CT-2:** Require methods and algorithms that allow plants to robustly operate and take corrective actions to abnormal situations using more detailed process

Rank	Key Solution	Issue Needing Resolution
		models and appropriate level of measurements.
18	**Solution IT-2-2:** Improve real time tools to identify and respond to cyber attacks while maintaining process integrity.	**Issue IT-2:** Lack of reliable cyber-security systems and standards on what is acceptable and how to cope with attacks.
19	**Solution: SC-2-1 and SC-2-2 (combined):** *Develop methods to integrate planning and scheduling by identifying key manufacturing constraints that need to be accounted for in planning; and *Develop algorithm and framework for multi-objectives (e.g., due date vs capacity utilization), multi-time period. Multi-scale approaches for integrating enterprise and plant levels	**Issue SC-2:** Need models to capture the big picture for enterprise management. There is a gap between enterprise level (planning level) and plant level (scheduling); ATP from the planning level needs to be operationalized at the scheduling level.
20	**Solution GL-5-1, GL-5-2, HR-4-2, and HR-2-3 (combined):** *Re-assess current approaches to what is taught, how it is taught, with what it is taught, and where it is taught, and development of curricula, pedagogical approaches, and educational resources that reflect the global reality; and *Develop a cohesive, vertically and horizontally integrated education and training programs, optimizing the balance between internal and external delivery. Could be combined with HR; and *Enhance emphasis on continuing education on industry specific technologies as part of job profiles; Professional organizations (ACS, AIChE) who would develop these courses from active collaborative initiatives among industrial thought leaders and academia; and *Develop national and International academic-industry cooperative field programs	**Issue HR-4, HR-2, and GL-5 (combined):** *Executive programs address business management, but not technology workforce continuing education; and *Technical education and training, both internal and external to the enterprise, which currently faces inhibitors, obstacles, and barriers for effectiveness and efficiency, such as government restrictions of mobility of the workforce; and *Discrepancy between academia and industry on future competence, capability and experience needs
21	**Solution MA-1-3:** Develop a management and technology structure for maintaining models as a corporate asset	**Issue MA-1:** The lack of a culture and system for creating, managing, valuing, and integrating models as enterprise assets that are maintained just like physical assets
22	**Solution PO-1-2:** Use top-down decomposition of a 'holistic optimization model' to develop components that avoid conflicting KPIs and develop synergy among	**Issue PO-1:** Integration: data, systems, operating functions and models are partly manual, not integrated nor fully coordinated.

Rank	Key Solution	Issue Needing Resolution
	collaborative applications and functions.	
23	**Solution PO-2-2:** Develop and apply model and data standards that stress overall benefits of modeling/optimization applications and resolve conflicting KPIs	**Issue PO-2:** Standards: Current Standards are inadequate; they are not complete and leave room for too much interpretation.
24	**Solution GL-1-2:** Create a core set of standards, best practices, common processes, and tool sets, which can be applied universally, and which contain enough levels of flexibility to adapt to specific local contexts.	**Issue GL-1:** Lack of understanding Contextual Diversity, which is composed of social, cultural, political, legal, fiscal, and economic issues at a local level, combined with a lack of standards and interpretations of intellectual property.
25	**Solution HR-1-2:** Design early career development programs to accelerate new employee's understanding and capabilities.	**Issue HR-1:** Loss of experience, technical knowledge, accumulated knowledge, and lack of development of next generation due to graying workforce.
26	**Solution CT-3-1:** Develop state estimation, fault detection and isolation using multiple heterogeneous and asynchronous inputs	**Issue CT-3:** Need methodologies for designing sensor networks for improved model-based state estimation and bias detection.
27	**Solution CT-3-3:** Design sensor networks to improve observability and bias-free state estimation and control	**Issue CT-3:** Need methodologies for designing sensor networks for improved model-based state estimation and bias detection.
28	**Solution GL-2-2:** Develop better costing models and of better pricing models that incorporate local input more formally and explicitly, and that establish economic assumptions, which are more reflective of local context.	**Issue GL-2:** Lack of global/local synergy, which addresses the need for awareness and understanding, at a local level, of prevalent mental paradigms; of the different interpretations on ES&H issues; of special language requirements; of cost and pricing variability; and integration of technology tools.
29	**Solution GL-3-2, and GL-3-3 (combined):** *Develop forums, mechanisms, and functional enablers that allow normalization, standardization, communication, validation, and collaboration between and among industry sectors. (External); and *Develop forums, mechanisms, and functional enablers that allow normalization, standardization, communication, validation, and collaboration between and among manufacturing facilities. (Internal)	**Issue GL-3:** *Need multinational, multistakeholder, and multidisciplinary integration, which includes cross-country, cross-industry, cross-plant, and cross-team global collaboration.

Rank	Key Solution	Issue Needing Resolution
30	**Solution CT-2-4:** Develop methods for the design of control systems using wireless sensors and actuators.	**Issue CT-2:** Need methods and algorithms that allow plants to robustly operate and take corrective actions to abnormal situations using more detailed process models and appropriate level of measurements.
31	**Solution GL-4-1, GL-4-2, and GL-4-3 (combined):** *Develop economic models for global acquisition and distribution of material resources for optimal manufacturing efficiency; *Develop a framework and practices for a global workforce that can be deployed locally for optimal manufacturing efficiency; *Develop a conceptual framework and implementation roadmap for the deployment of standard core processes and technologies locally for optimal manufacturing efficiency.	**Issue GL-4:** Need to improve resource optimization in terms of what needs to be done, how it is best accomplished, where it should best be done, and what resources should be used.

1.7 Next Steps - Share Workshop Results and Develop Roadmap

A rich set of issues and solutions was created during the workshop; however there was insufficient time to develop an initial roadmap for each area. Therefore, the next steps are to communicate the workshop results and develop a roadmap (like the example shown below in Figure 2) that lays out:

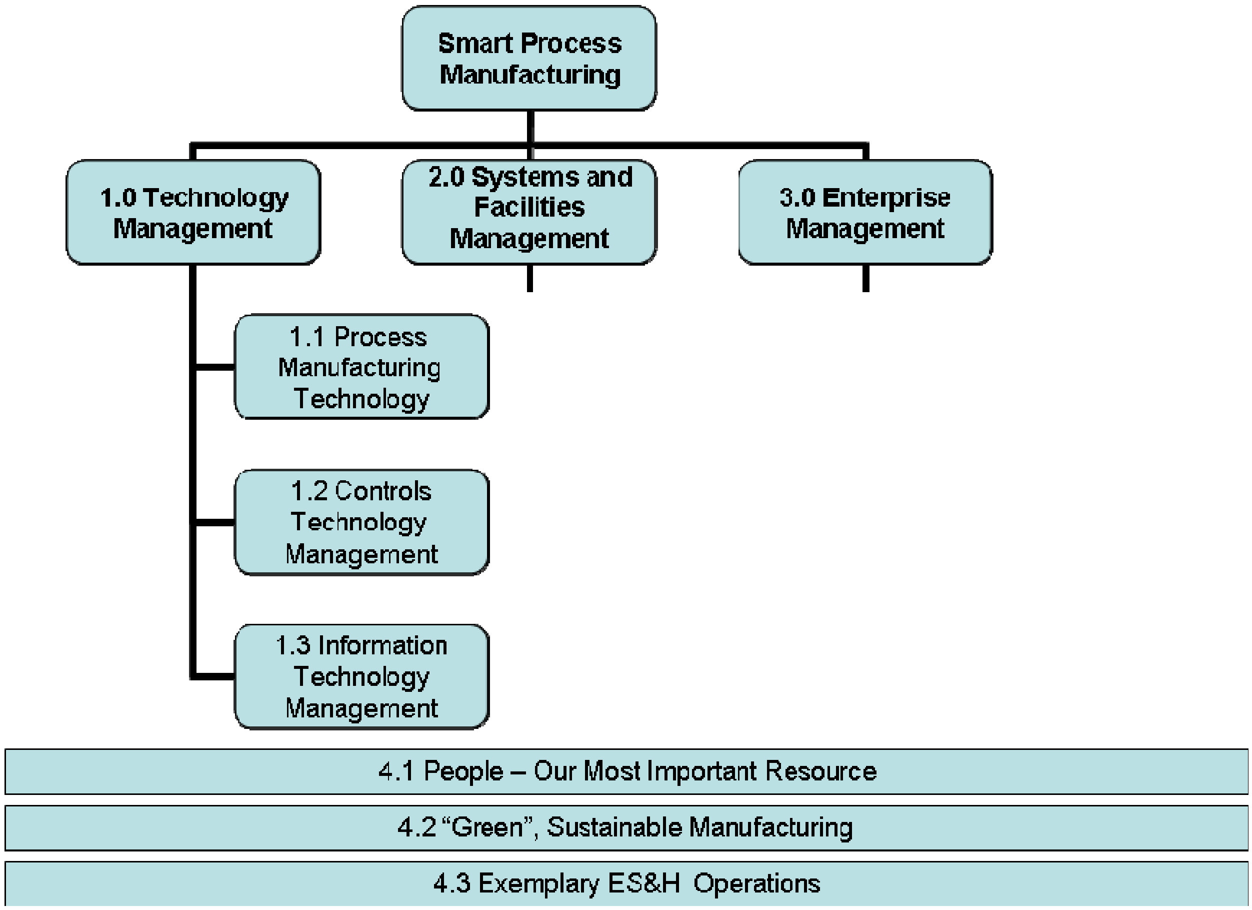
- a timeline for delivery of the solutions,
- a rough-order-of-magnitude estimate of required financial resources, and
- metrics by which to measure progress

DoD Orthotics & Prosthetics 2.0 Product Life-cycle Management				Timeline										
WBS	Issue and Solution	PRI	Dur-ation	FY 07	FY 08	FY 09	FY 10	FY 11	FY 12	FY 13	FY 14	FY 15	FY 16	FY 17
1	Modeling and Simulation Limitations													
1.1	Complete User Analysis and Model Definition	H	3y											
1.2	Prioritized Models Needs List	H	3y											
1.3	Gap Analysis and Filling of Voids	H	10y											
1.4	Scenario-based and Interactive Conceptual Design	H	10y											

Figure 2. The Roadmap template provides a common framework for capturing and organizing technology development requirements to support more detailed planning.

The subsequent roadmap and supporting information will be managed as a living document for use by the SPM-EVO to initiate actions that will mature the roadmap and greatly accelerate the advancement of smart process manufacturing.

2.0 TECHNOLOGY MANAGEMENT



[[Note: the workshop pillar team wanted to change 1.2 to "Controls and Automation Technology"]]

Technology Management addresses the determination of all the technological resources required to sustain, protect, and improve operations of the manufacturing enterprise. Typically, many types of technology are involved, and they act as enablers for both local and cross-enterprise/global issues: specialized processes and systems, tools, control systems, modeling capabilities, and the people whose knowledge and practical expertise make the processing successful. Even the current and archived data streams from production sensors are a resource that can yield insights and competitive production improvements.

The challenges of technology management are quite different for new production facilities and for existing facilities faced with retrofitting to exploit new technologies. It is usually easier to create "green", sustainable operations with new processes.

Subtopics included in the scope of **Technology Management**:

- **Process Manufacturing Technology** – The provision of the capabilities and processes required to transform raw materials into a useful product. The processes may include chemical transformation of materials, intensification of materials, molecular transformation, or other processing and packaging.
- **Controls and Automation Technology** - The provision of a sense-analyze-control environment and associated automation capable of ensuring that all critical parameters operate within control limits. Controls technology management includes providing needed all information and communications and ensuring the proper response to any abnormal condition. This foundation element includes analysis of existing conditions to predict and proactively respond to a changing environment.
- **Information Technology Management** **–** The provision of information systems and communications technology to ensure that information concerning all aspects of the enterprise is captured, processed, and integrated into the enterprise knowledge store. The result is the assurance that the right information is always available, at the right time, and in the right format. This foundation element includes the provision of a secure environment that protects the interests of the company and the individuals and is compliant with all relevant regulations.

2.1 Current State Assessment for Technology Management

Several themes emerge from expert discussions of technology management for small process manufacturing. Increasing use of technology has led to mountains of data and associated data management problems. However, the relationships of data to underlying processes and material properties is not well enough understood, the data is not integrated between systems, and so important data is not fully exploited. The challenge is to understand relevant technologies and their associated data well enough to target acquiring and processing only the needed data. There is however increasing use of models and efforts to grow their scope, interoperability, and applicability to production operations - not just design.

Technology investment decisions tend to be made with too short-term a view, expecting a payoff too quickly. Operations decisions tend to be highly reactive instead of proactive. A frustrating daily concern is that process engineers have to spend too much time worrying about cybersecurity and other IT details—software complexity and maintenance, version control, etc.

An often overlooked truth in technology management discussions is the difficulty and quite different economic considerations in upgrading existing facilities to take advantage of data and available technology, as opposed to “green field” installations.

A widely discussed concern is that current engineering education at the B.S. level does not prepare students well for the manufacturing-specific tasks they will face in actual production facilities. Needed topics frequently mentioned include optimization of process systems, data rectification, and other manufacturing skill sets such as powder technology.

2.1.1 Process Manufacturing Technology

Companies still tend to design their products and processes based on specific customer wants and the lowest cost. There is increasing realization of the need to optimize design and production over the entire product life-cycle, with greater consideration of larger business and sustainability objectives. Even when the organization has ongoing research and development efforts, the results of those efforts are often not integrated with production engineering even within the same company. Process design is faced with challenges of increasing complexity in integrating multiple objectives and technologies, yielding multidimensional optimization problems. There is growing movement to sustainability, reuse, and approaches like pinch technology in facing current process design problems.

2.1.2 Controls and Automation Technology

Digital control systems are in wide use, generally based on PC-level machines and Microsoft architectures. Smart instruments are in common use, but the challenge remains to integrate models built for specific functions and make wider use of them, for example for safety and environmental purposes.

There is pressure to allow more input variability while production requirements mandate less output variability. Consequently, control systems need better ability to quickly determine the varying physical properties of feedstock and respond appropriately. In seeking this capability, the challenge is understanding, modeling and successfully moving operations from bench scale to production scale control systems.

2.1.3 Information Technology Management

There is a general movement from proprietary to open systems, and growth in mobile computing and wireless communication. However, there is a big need to make current technology capabilities available to design and production engineers and operators in forms that can easily be used, automatically maintaining required security, while not requiring extensive training or deep understanding of either the underlying technology or the application software complexities. In addition, better tools are needed for understanding and managing the value of data streams.

Current State Assessment for Technology Management

Technical & Intellectual Barriers and Deficiencies	State of Art / Predominant Practice	Best Practices and Emerging Research
Technology Management		
• Disparate data; lack of interoperability; data models or definitions not useful in multiple systems • Poorly used data • Poor quality of process variable measurements • Under-utilization of assets of all sorts, including models, automa-	• We calculate net present value, single-variant economics • Data are collected and archived, but not mined or exploited • Process modeling used predominantly in R&D environment, but not used later during production operations	• Some companies doing life-cycle analysis, multivariate analysis. Pockets of excellence in every company. • Human-plant interface modeling, training, console designs, etc. –see work done by Abnormal Situation Management Consortium • Virtual networks connecting special

Technical & Intellectual Barriers and Deficiencies	State of Art / Predominant Practice	Best Practices and Emerging Research
tion systems, people, tools • Companies tend to have too short-range view of technologies; may expect pay-off too quickly. Short-term economics. • Inadequate supply of people, training, skill sets; workforce trends. Conflict between short- and long-term business objectives. • Lack of tools for dissemination of knowledge • Difficult to connect profitability objective with process control objectives • Insufficient meaningful metrics for valuing different technologies or facility management techniques	• Highly reactive operations instead of pro-active • Life-cycle of automation assets is driven too much by vendors, not by industry needs • Complexity of software applications has escalated beyond capabilities of typical workers; requires IT and engineering expertise to use them • Cyber security now intrusive, intrinsic to all systems, requires considerable IT implementation • Engineering improvements usually one-off, custom implementations; not useful in multiple environments • Pressure to reduce IT spending, while IT role as required enabler keeps growing in all areas. Has impact on control, etc.	interest technologies of multiple companies, e.g., extrusion technology • Safety practices: standardization of modeling, training, and implementation among some companies. Dow is good example. • “Technology guardian” management programs in some companies • Lots of research on new technologies, like nano- or bio-technology, looking for best areas of applicability • Pervasive model development, with higher fidelity and reality, looking for best areas of applicability • Research on sensor networks and wireless, but not used enough; looking for best areas of applicability • Groups looking at new technologies, how to take them to commercial viability
Process Manufacturing Technology		
• Understanding relationships of process and associated data • Would like to be able to target information then acquire it, as opposed to collect everything and sort later • Difficult to upgrade existing facilities to take advantage of data and available technology • Data streams not integrated and managed from discovery through to commercialization • Disconnects between research and engineering even within same company • Instrumentation cost versus value • Extracting valuable information from large data sets • Complexity when enhancing product reusability • Managing multidimensional complexity – design issue • Need better linkages between process and control models with physical property models	• Some product models immature (powder versus fluid flow) • Not fully integrating operations and safety into development and design phase • Limits on design process • Product design is based on specific product (wants and needs of customers) – optimize from customer perspective. Need to optimize design from perspective of entire product life-cycle • Product optimization not accounting for all economic factors • Currently build product to lowest product cost or life-cycle cost. Not exploring business objectives or global impact • General practice is corrective innovation as opposed to doing it right initially Try to minimize harmful transformations in a process • Can be considered FCCU (Fluidized Catalytic Cracking Unit) expert if you are correct 15% of the time! • Multiple process models for each asset, not integrated into singular model covering entire process	• Early signs of sustainability focus, e.g. a shift to from selling a product to a service (leasing) • Some companies have begun leasing carpet as opposed to selling—exploiting product reusability • Water desalination – moving from sieve-filtering to distillation (less energy intensive) • Elimination of separation steps by using shape specific reactions • Leased catalyst – refurbish and re-use • Methodologies emerging for design based on product life-cycle and comprehensive business objectives • Pinch technology being taught in many undergraduate curriculums – design heat integration to increase energy efficiency • Pinch technology for carbon • Pinch technology for materials processing (separation agents etc.)
Controls and Automation Technology		

Technical & Intellectual Barriers and Deficiencies	State of Art / Predominant Practice	Best Practices and Emerging Research
• Control systems need better physical property models – need flexibility to compensate for feed quality changes. Input variability increasing and output variability decreasing. • Need to understand the role of control technology as you progress from bench scale to production • Need tools for rapid determination of physical properties • Integration of controller information is evaluated/designed at level of user not at high levels • Collaborate between controls/fault detection/monitoring etc. to define data requirements • Targeting correct goals (emissions, product quality) reduced to instrumentation and software • Hardware costs – future processes need to define data requirements and design process & hardware requirements accordingly • Need to develop unified multipurpose model allowing different functional areas to use different aspects of same data • BS education does not cover topics from process systems engineering side such as optimization and data rectification • Need better integration of process control systems (real-time level) with process operations (fault diagnosis and management) • Need automatic control system using networked sensors and actuators • “Smartness” for controls needs to occur starting in design phase of product • Introduction of bias in measurement equipment • Need to aggregate information from multiple distributed models – to get the right data to the right place • Pace of change – difficult to keep up and incorporate useful tech-	• Have generally moved from single analog to digital control architecture. Smart instruments in common use. • Moving from proprietary to open systems – use of Ethernet and Windows-based platforms as opposed to proprietary platforms. • Using off-the-shelf technology, mostly Microsoft • Security oriented, but off-the-shelf software is vulnerable to bugs and viruses • Focus on measurement technology is at bench scale – missing opportunity to test control technology • Using PC-level computational tools • Dedicated measurements, valves, logic controllers for safety systems • Typically do not take advantage of data from different sources – data which would be useful in the design phase. • Models developed late, close to manufacturing phase of product lifecycle • Models built by different people at different times for different, specific purpose with little similarities outside of data.	• Wireless technology in growing use; creates new opportunities for control but issues such as power management and security • Mobile smart devices communicate with sensors • Some inclusion of control in process design – new opportunities for reaction engineering • Use of models to identify control parameters for meta-stable systems • Robust model-based control – self regulating • Sensor diagnostics - Emerson does statistical analysis at sensor level which is useful in monitoring • New ways to utilize sensor diagnostics to evaluate process state - sensor sends data to control system for complex analysis • More industrial use of supercomputers • Other uses of multi-core computing – can take on more control tasks. Can be used for predicting plant behavior, and used as tool for operator training. • Use of control system data for tasks other than process control - environmental, safety, etc. • Beginning to re-evaluate safety systems to determine the best shutdown method. Use finesse and graceful modification or shut down, instead of immediate valve shutdown or flares • Smart plant evaluates and assists with the best shut-down methodology • Better fidelity simulations being used to define operating regime for different feedstock. Modeling a greater number of molecular species or ‘lumps’ and track through process • P&G is developing methods to quantify customer-defined preferences of product properties and then correlate laboratory measurements with consumer desires (e.g., how do you quantify ‘hair volume’ and correlate to laboratory measurements) • Lamar University’s dynamic simula-

Technical & Intellectual Barriers and Deficiencies	State of Art / Predominant Practice	Best Practices and Emerging Research
nology • Need to standardize software and models for greater interoperability • Difficult to make industrial use of supercomputers due to perception of specialized computing needs, requirement to modify computational approach • Need to integrate Safety more closely as part of the control process. ISA-84 concerns recording and reporting of interlock trip area. Safety data insulated from DCS • Need to determine economic value of creating more and more detailed physical property models. Economics tied to value and volume of molecule. • Models are corrective based on different formulations (rheological considerations) • How to quantify user needs		tion of start-up procedures reduced flares by 70% • Methodologies for optimal minimum cost design of instrumentation networks for control, fault identification, and performance monitoring (University of Oklahoma) • Univ. of Oklahoma working on economic value of information-driven instrumentation network design.
Information Technology Management		
• Need better understanding of the economic value of information • Lack of integrated data stream management through discovery to commercialization • Lack of trained people and knowledge dissemination in powder technology • Need to put state of the art technology in a form that can be easily used BS level employees • Operations personnel do not have access to high-level models for process diagnostics • Engineering education does not prepare students for manufacturing-specific tasks • Importance of cyber-security is a challenge, and diverts resources from the “real work” • Visualization of large masses of data – how to assimilate for specific tasks • Need to mine data to make good control decisions	• BS level engineers can use software for higher level tasks without deep understanding (optimization) • BS engineering programs are trending towards bio-engineering as opposed to process systems and manufacturing skill sets.	• New engineers shifting towards energy field instead of pharmaceutical • Some use of desktop supercomputing capabilities with parallel processing. Challenge is developing software to take full advantage of multi-core architecture • Emergent data mining capabilities – leverage techniques in other fields such as particle physics and bioinformatics.

2.2 VISION FOR TECHNOLOGY MANAGEMENT

In the future, smart plants will be developed, designed, and operated using molecularly informed engineering. They will operate in a robust fashion. Smart plants will be proactive with respect to faults, address market needs and environmental health and safety considerations, and be integrated seamlessly throughout and within the greater enterprise via cyber infrastructure.

Models and all associated knowledge will be maintained and enriched as part of the plant's routine operation. Models will be developed to the level of detail needed, including multi-scale modeling to achieve the higher fidelity needed for some functions. Management will support this activity because operations and business goals will be closely integrated; business goals will be directly translated into technology plans. This will enable flexibility of operations, robustness, agility, and the ability to change product streams quickly (especially in batch) or to make grade changes (for continuous processing).

Notes and Attributes of the vision for Technology Management:

The following attributes of the vision for Technology Management were gathered from workshop participants. Letter codes indicate Industrial/Technological (I) and Intellectual/Academic (A) attributes.

- The domain expertise and knowledge of experts is captured and made available for later use. (A)
- Full utilization of data gathered in plants; e.g., ability to assimilate data and use it to validate models. (I)
- Big-picture thinking; investment for the future instead of short-term benefit. (I)
- Flexibility of operations; robustness, agility, ability to change product streams quickly (especially in batch); for continuous processing, will have ability to make grade changes, etc. (IA)
- Operations and business goals are closely integrated; business goals are translated into technology plans. (I)
- Asset life-cycle analysis routinely used in business decisions. (IA)
- Fully evolved standards are developed and in accepted use to handle life-cycle analysis of assets, global business functions, and environmental concerns. (I)
- Business leaders will trust and make use of modeling and other technologies in their investments and decision making. (I)
- Models and their included knowledge are maintained and enriched as part of the plant's routine operation, and management supports this (includes multi-scale modeling to achieve higher fidelity); models will be developed to the level of detail needed for intended function. (IA)
- Process models and simulations are the tools not just for experts, but conveniently available and used as part of routine operation; inherent and pervasive. (IA)

- Zero emissions and zero incidents are adopted by management as a priority in the design and operation of plants. Management merges social norms, government requirements and enterprise objectives into a singular set of goal. (I)
- Long-term prediction and planning for environmental regulations. (IA)

2.2.1 Vision for Process Manufacturing Technology

Smart manufacturing will be in common practice, using molecularly informed engineering of sufficient accuracy to enable fully customized products and sustainable processes. Processes will be designed to maximize the number of productive transformations and reduce the number of harmful transformations and corrective steps, undesired byproducts and waste. A single, universally recognized set of criteria for evaluating risks and potential mitigations will be applied from the process inception through the process life-cycle, from design into manufacturing.

Knowledge- and data-driven models based on first principles will be used for design on every process, and will identify deviations from optimal operation. Plants will not only use the best models, but they will have appropriate instrumentation to assist in the process. Existing plants will be able to apply cutting-edge technology to cost-effectively maintain and refit operations. Furthermore, the long-term implications and resulting economic value of adding technology to achieve zero incidents and zero emissions processing will be understood and exploited.

Notes and Attributes of the vision for Process Manufacturing Technology:

The following attributes of the vision for Process Manufacturing Technology were gathered from workshop participants. Letter codes indicate Industrial/Technological (I) and Intellectual/Academic (A) attributes.

- Best models (first principles, knowledge and data driven) will be used for design on every process, identifying deviations from optimal operation. Plants not only will use best models, but will have appropriate instrumentation to assist in the process. (I)
- Formulate today – manufacture tomorrow. Significantly reduce time from design to manufacturing with the ability to efficiently customize every product. (I)
- Predictive tools incorporating molecular properties will assist in customizing product properties. (IA)
- Pharmaceuticals will be personalized based on individual genetics. (IA)
- Models that simulate processes will be good enough to reduce or eliminate the need for product testing. (IA)
- Processes will be designed to minimize or eliminate by-products and waste. (IA)
- Production will have zero emissions; that is, it will have no emissions above those expected or that occur naturally in the raw materials. (I)
- The plant’s resources will be used to continually improve processes to trend towards zero emissions. (IA)
- There will be zero product recalls – product and process design will detect and account for all unintended consequences. (I)

- The long-term implications and resulting economic value of adding technology for zero incidents and zero emissions processing will be understood and exploited. (IA)
- Existing plants will be able to apply cutting edge technology to cost effectively maintain and refit operations. (I)
- Safety integrated level is one or below for all facilities. (I)
- There will be a single, universally recognized set of criteria for evaluating risks and potential mitigations that are applied from the process inception through design into manufacturing, i.e. throughout the process life-cycle. (IA)

2.2.2 Vision for Controls and Automation Technology

Plant automation advances will enable a transformative shift in the efficiency and sustainability of both existing and future facilities. Smart plants will be robust, proactive and able to predict impending trouble and take proper corrective action before serious consequences occur, using monitoring, controls, and actuator and sensor networks. Plants will align their operational objectives with overall business goals in real time, based on market needs as well as environmental, health and safety considerations.

Sensors for real-time physical, chemical and composition property measurement will be smaller, simpler, and cheaper. Different types of models (statistical, first principles, business, supply chain, physical properties, etc.) will be combined and integrated in a hierarchical architecture to appropriate level of detail to realize intelligent operation toward business objectives. The resulting models and monitoring and control algorithms will be understood at a level that will provide universal availability and uptime (continuously productive operation) and will bring about safer operation and better product quality.

Notes and Attributes of the vision for Controls and Automation Technology:

The following attributes of the vision for Controls and Automation Technology were gathered from workshop participants. Letter codes indicate Industrial/Technological (I) and Intellectual/Academic (A) attributes.

- Real-time, rigorous, first principles models will be running on every process, identifying any deviations from optimal operation. (IA)
- Plant will use these models to be proactive and predict impending trouble and take proper corrective action before serious consequences occur. (IA)
- Smart assets will have awareness and intelligence to sense, communicate, and support life-cycle analysis and the adaptability of the business to attain goals. (IA)
- Different types of models (statistical, first principles, business, supply chain, physical properties, etc.) will be combined and integrated in a hierarchical architecture to appropriate level of detail to realize intelligent operation. (I)
- New methodologies will enable design of sensor and actuator networks with accuracy levels and software redundancy to allow models to function appropriately and provide fault-tolerant operation and bias free data. (A)

- Controls and automation will be understood at a level that provides universal availability and uptime (continuously productive operation). (A)
- We will have better online, instantaneous measurement capabilities for small-scale bench research facilities to improve the design and control of process. (IA)
- Models and work processes that use sophisticated analysis techniques such as spectroscopic, IR, NIR, NMR, and Raman measurements will be available for online sensing. (A)
- Sensors for real-time physical, chemical and composition property measurement will be smaller, simpler, and cheaper. (A)
- Robust models and monitoring and control algorithms will bring about safer operation and better product quality, and will also enable reduction or centralization of operations personnel. (A)
- Operator training and continuing education will give them the skills sets to utilize complex models. (I)

2.2.3 Vision for Information Technology Management

The cyber infrastructure will be functional, foolproof, ubiquitous, secure and invisible. (Chemical engineers will no longer have to worry about IT details.) Domain knowledge will be available and trustworthy to all who need it, with seamless integration of different software tools.

Notes and Attributes of the vision for Information Technology Management:

The following attributes of the vision for Information Technology Management were gathered from workshop participants. Letter codes indicate Industrial/Technological (I) and Intellectual/Academic (A) attributes.

- Owner/operators will not have an IT burden and will be able to concentrate on their processing tasks. (I)
- There will be better isolation and separation of detailed concerns between domain applications (engineering, accounting, etc.) and the IT infrastructure that supports them. (I)
- Computing and memory capacity will no longer be a limitation – it will be cheaply and easily available. (A)
- Cyber security will be foolproof and effective. (A)
- Standards will enable seamless data transfer among different systems and platforms, including via wireless communication. (A)
- Consensus on data standards will be achieved in a timely manner. (I)
- Software tools and their interfaces will be standardized so that operations personnel can take advantage of complex models and plant data for job performance and training. (IA)
- The human-machine interface will support multiple types of users and applications appropriately at the task level. (A)
- A single, integrated knowledge management system will mean no islands of data. (A)

- No information will be lost or corrupted. (IA)
- Any changes to information or processes will be automatically captured and managed via an integrated management of change system. (I)
- Related and integrated data are fully accessible and beneficially exploited to make business decisions. (I)

2.3 Issues and Solutions for Technology Management

Issue TM-1: Lack of sufficient quality, availability and use of data (all types)

Issue TM-2: Insufficient fidelity, maintainability, validity, use and reuse of models

Issue TM-3: Lack of tools for capture, representation and integration of knowledge, and for dissemination of knowledge to point of need/use

Issue TM-4: Mismatch of software (and other IT) functionality and interface complexity with typical user (engineer or operator) needs and capabilities

Issue TM-5: Lack of meaningful metrics for evaluating different technologies or facility management techniques

Issue TM-6: Lack of simple means for industrial collaboration to organize and fund this vision. Industry-academic interface and IP issues prevent open sharing of knowledge.

> Solution suggestions:
> Use AIChE model for academic-industrial alliance.
> ES&H issues are in public interest and can be leveraged to facilitate collaboration.
> Create software tools that can be used across industries.

Issue TM-7: Lack of real industry problems and experience for use in academic research.

Issue TM-8: Need for collaborative funding and research between industry, academia, and government.

Issue TM-9: Need to involve non-chemical engineering researchers (mathematicians, computer scientists, physicists, etc.) in problem solving (such as mining large data sets).

2.3.1 Issues and Solutions for Process Manufacturing Technology

Issue PM-1: Retrofit of existing plants presents unique challenges in making the introduction of new technology to existing plants cost-effective.

Issue PM-2: Design must reconcile multiple objectives and not focus solely on cost.

Issue PM-3: Need to design plant processes and instrumentation for fault-tolerant behavior

Issue PM-4: Need to develop models and algorithms to enable the molecularly informed design and control in a way that easily exploits emerging computer technologies. Need smart data collection and processing.

Issue PM-5: Lack of educated chemical engineers at all levels (practitioners and research) prepared to work in smart plant environment. Need for professional Masters of Engineering degree.

**Note: Industry sees MS degree as positive from the perspective of career advancement and the potential for upper technical management in engineering, although the short-term benefits may not be evident.

Issue PM-6: Need to decide whether data mining of large data sets is more beneficial than determining what meaningful data is needed and capturing only that.

Issue PM-7: Resources are constrained in US plants due to global economic factors.

Issue PM-1: Retrofit of existing plants presents unique challenges in making the introduction of new technology to existing plants cost-effective.	
Solution PM-1-1	Create a common set of metrics that can be used by industry to evaluate the economic impact of ES&H considerations as well as social responsibility.
Solution PM-1-2	Develop hybrid control architectures for improving the monitoring, reliability and performance of wireless control systems, so that wireless control systems are as robust and reliable as wired control systems.
Solution PM-1-3	Develop methodologies and tools to evaluate the opportunities for advantageous process retrofits (for example heat integration and increased safety).

Issue PM-2: Design must reconcile multiple objectives and not focus solely on cost	
Solution PM-2-1	Charter an independent group of academic and industry participants to create a universal set of metrics for evaluating the economic impact of process robustness, flexibility (ability for the process to handle multiple feedstocks), and fault-tolerance.
Solution PM-2-2	Develop rules and standards for evaluating process designs that include additional factors as well as cost and quality.
Solution PM-2-3	Incorporate the additional factors such as ES&H and carbon footprint into tools used for process synthesis.

Issue PM-3: Need to design plant processes and instrumentation for fault-tolerant behavior and use bias-free data.	
Solution PM-3-1	Develop tools that rate the fault-tolerance of an early process design. Make pervasive use of process design methodologies that incorporate dynamic simulation to minimize and isolate faults and evaluate process operability on a real-world scale.
Solution PM-3-2	Develop tools to increase the speed and efficiency of methodologies that integrate 1) instrumentation design for control, fault detection and identification, and 2) parameter estimation/production accounting into a single pro-

Issue PM-3: Need to design plant processes and instrumentation for fault-tolerant behavior and use bias-free data.	
	cedure.
Solution PM-3-3	Explore ways to merge tools that evaluate the fault-tolerance of a design with the process instrumentation, and implement these tools at the early design stage.

Issue PM-4: Need to develop models and algorithms to enable the molecularly informed design and control in a way that easily exploits emerging computer technologies. Need smart data collection and processing.	
Solution PM-4-1	Develop molecular models that can provide a quantitatively accurate description of a broad range of thermophysical properties applicable over variations in the thermodynamic phase, mixture composition and thermodynamic state.
Solution PM-4-2	Develop theories and algorithms that enable the rapid evaluation of thermophysical properties from a molecular model in a way that exploits emerging microprocessor technologies.
Solution PM-4-3	Develop multiscale particulate models that link individual particle and bulk behaviors.
Solution PM-4-4	Develop control methods using multiscale process models
Solution PM-4-5	Employ solutions from other fields that utilize large data sets (physics, computer science, bioinformatics, etc.) for smart data collection and analysis.

Issue PM-5: Lack of educated chemical engineers at all levels (practitioners and research) prepared to work in smart plant environment. Need for professional Masters of Engineering degree.	
Solution PM-5-1	Create a forum for involving industry and academia in determining chemical engineering curricula that provides undergraduate and graduate students an education needed for smart manufacturing.
Solution PM-5-2	Create a collaborative space and database for the continual exchange of ideas needed for facilitating ongoing curricula change to better reflect the needs of industry.
Solution PM-5-3	Develop a comprehensive description of the chemical engineering body of knowledge, that allows universities to tailor curricula and continuing education (e.g. distance learning programs) around specific industries.
Solution PM-5-4	Provide professional recertification and continuing education of practicing engineers

2.3.2 Issues and Solutions for Controls and Automation Technology

Issue CT-1: Need new sensor technology that is smaller, simpler, and cheaper for measuring online physical, chemical, and composition properties– consistent with the needs of the molecularly informed smart plant.

Issue CT-2: Require methods and algorithms that allow plants to robustly operate and take corrective actions to abnormal situations using more detailed process models and appropriate level of measurements.

Issue CT-3: Need methodologies for designing sensor networks for improved model-based state estimation and bias detection.

Issue CT-4: Need support for the evolving role of the operator including increased knowledge, more testing, and use of complex models.

Issue CT-5: Difficulty justifying expenditure to accomplish smart manufacturing using conventional economic criteria.
Solution 5: Develop means to monetize ES&H, sustainability and justify expenditures.

Issue CT-6: Difficulty of designing control strategies to successfully incorporate more detailed process models and appropriate level of measurements.

Issue CT-7: Computational challenges with reconciling process measurements and model predictions.

Issue CT-8: Shift to common off-the-shelf technologies and Microsoft platforms has created a significant challenge to the users and suppliers, taking resources from value-added activities.

Issue CT-1: Need new sensor technology that is smaller, simpler, and cheaper for measuring online physical, chemical, and composition properties– consistent with the needs of the molecularly informed smart plant.	
Solution CT-1-1	Develop sensors for direct, reliable, online composition measurement.
Solution CT-1-2	Develop sensors and modeling tools for estimating online material microstructure properties.
Solution CT-1-3	Create widely available database to communicate industrial sensor needs, enabling vendors to accelerate the development of composition sensors. Discover the common relationships covering all types of online compositional measurements and exploit them for common benefit.
Solution CT-1-4	Provide better tools for defining and predicting commercial environments in which the sensors and analyzers will operate.

Issue CT-2: Require methods and algorithms that allow plants to robustly operate and take corrective actions to abnormal situations using more detailed process models and appropriate level of measurements.	
Solution CT-2-1	Develop methods for fault detection and isolation, accounting explicitly for controller design as well as fault tolerant control.
Solution CT-2-2	Provide generic algorithms that can be applied to multiple, diverse processes without requiring process-specific programming.
Solution CT-2-3	Develop associated actuator and sensor instrumentation networks to accomplish fault tolerant control, that is compatible with other functions such as quality control, production accounting, online optimization, etc.
Solution CT-2-4	Develop methods for the design of control systems using wireless sensors and actuators.
Solution CT-2-5	Develop tools supporting creation of fundamental models for automated root-cause analysis that provides entire plant coverage, and can present information in a manner that can be easily understood and acted upon by operations personnel.

Issue CT-3: Need methodologies for designing sensor networks for improved model-based state estimation and bias detection.	
Solution CT-3-1	Develop state estimation, fault detection and isolation using multiple heterogeneous and asynchronous inputs
Solution CT-3-2	Develop algorithms that allow the use of multiple, cheap wireless sensing devices to replace hardwired reliable instruments in closed loop control.
Solution CT-3-3	Design sensor networks to improve observability and bias-free state estimation and control.

Issue CT-4: Need support for the evolving role of the operator including increased knowledge, more testing, and use of complex models.	
Solution CT-4-1	Develop solution using distributed computing and mobile devices.
Solution CT-4-2	Develop operator guidance tools that incorporate better human factors engineering of the operator console/cockpit.
Solution CT-4-3	Refine the human machine interface to increase operator usage of complex models.
Solution CT-4-4	Develop cheaper, flexible and adaptable operator training tools with a focus on best shutdown and startup procedures

Issue CT-5: Difficulty justifying expenditure to accomplish smart manufacturing using conventional economic criteria.	
Solution CT-5-1	Develop means to monetize ES&H, sustainability and justify expenditures.

2.3.3 Issues and Solutions for Information Technology Management

Issue IT-1: No automated, integrated knowledge management or business intelligence systems, yielding islands of data. Management of change and data still largely a manual issue

Issue IT-2: Lack of reliable cyber-security systems and standards on what is acceptable and how to cope with attacks.

Issue IT-3: Difficulty of integrating data between different systems and sources.

Issue IT-4: Need to create interface for easy assimilation and presentation of multiple systems and applications and the ability to act thereon.

Issue IT-5: Lack of sufficient computing power and numerical methods for exploiting parallel processing for multiphase and multiscale modeling.

Issue IT-6: Owner, operators and suppliers burdened with IT

Issue IT-1: No automated, integrated knowledge management or business intelligence systems, yielding islands of data. Management of change and data still largely a manual issue.	
Solution IT-1-1	Need to develop a simple and efficient means to backfill existing data into new database technologies.
Solution IT-1-2	Create a search engine that operates across multiple legacy systems as well as positioning for future technologies.
Solution IT-1-3	Develop automated approaches to change management.
Solution IT-1-4	Develop standardized P&ID modeling software that assists in model integration.

Issue IT-2: Lack of reliable cyber-security systems and standards on what is acceptable and how to cope with attacks.	
Solution IT-2-1	Develop effective and unobtrusive virus protection and firewall tools.
Solution IT-2-2	Improve real-time tools to identify and respond to cyber attacks while maintaining process integrity.

Issue IT-3: Difficulty of integrating data between different systems and sources.	
Solution IT-3-1	Develop widespread standards for data formatting and integration that are embraced by industry and required by vendors.
Solution IT-3-2	Develop a baseline IT format that optimizes and integrates the data flow between different systems and platforms, and create incentives to accomplish this mission.

Issue IT-4: Need to create interface for easy assimilation and presentation of multiple systems and applications and the ability to act thereon.	
Solution IT-4-1	Extend concept of universal operator interface to engineering and management interfaces.
Solution IT-4-2	Develop human factors toolset that allows easy interface creation and thus maximizes the value of underlying models and data analysis.

Issue IT-5: Lack of sufficient computing power and numerical methods for exploiting parallel processing for multiphase and multiscale modeling.	
Solution IT-5-1	Provide software tools for creating seamless and transparent solutions that takes full advantage of the multicore, parallel processing architectures for process modeling.

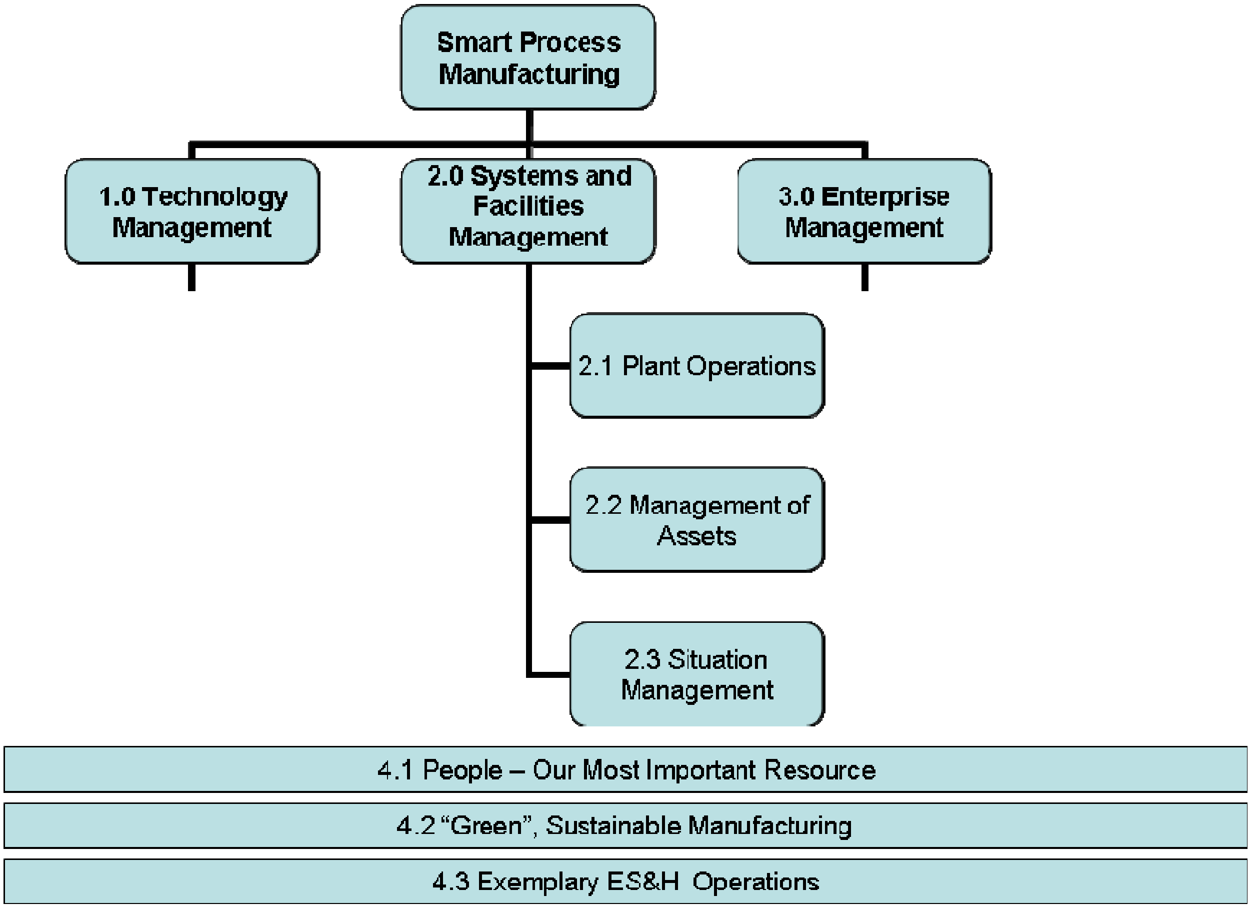
2.4 Top Priority Solutions for Technology Management

Issue PM-4: Need to develop models and algorithms to enable the molecularly informed design and control in a way that exploits emerging computer technologies. Need smart data collection and processing.	**Solution PM-4-2:** Develop theories and algorithms that enable the rapid evaluation of thermophysical properties from a molecular model in a way that exploits emerging microprocessor technologies.
Issue PM-2: Design must reconcile multiple objectives and not focus solely on cost	**Solution PM-2-1:** Charter an independent group of academic and industry participants to create a universal set of metrics for evaluating the economic impact of process robustness, flexibility (ability for the process to handle multiple feedstocks), and fault-tolerance.
Issue PM-3: Need to design plant processes and instrumentation for fault-tolerant behavior and use bias-free data.	**Solution PM-3-1:** Develop tools that rate the fault-tolerance of an early process design. Make pervasive use of process design methodologies that incorporate dynamic simulation to minimize and isolate faults and evaluate process operability on a real-world scale.
Issue CT-2: Require methods and algorithms that allow plants to robustly operate and take corrective actions to abnormal situations using more detailed process models and appropriate level of measurements.	**Solution CT-2-4:** Develop methods for the design of control systems using wireless sensors and actuators.
Issue CT-3: Need methodologies for designing sensor networks for improved model-based state estimation and bias detection.	**Solution CT-3-1:** Develop state estimation, fault detection and isolation using multiple heterogeneous and asynchronous inputs
Issue CT-3: Need methodologies for designing sensor networks for improved model-	**Solution CT-3-3:** Design sensor networks to improve observability and bias-free state estima-

2.4 TOP PRIORITY SOLUTIONS FOR TECHNOLOGY MANAGEMENT

based state estimation and bias detection.	tion and control
Issue CT-2: Require methods and algorithms that allow plants to robustly operate and take corrective actions to abnormal situations using more detailed process models and appropriate level of measurements.	**Solution CT-2-1:** Develop methods for fault detection and isolation, accounting explicitly for controller design as well as fault tolerant control.
Issue CT-2: Require methods and algorithms that allow plants to robustly operate and take corrective actions to abnormal situations using more detailed process models and appropriate level of measurements.	**Solution CT-2-3:** Develop associated actuator and sensor instrumentation networks to accomplish fault tolerant control, that is compatible with other functions such as quality control, production accounting, online optimization, etc.
Issue IT-2: Lack of reliable cyber-security systems and standards on what is acceptable and how to cope with attacks.	**Solution IT-2-2:** Improve real time tools to identify and respond to cyber attacks while maintaining process integrity.
Issue IT-3: Difficulty of integrating data between different systems and sources.	**Solution IT-3-2:** Develop a baseline IT format that optimizes and integrates the data flow between different systems and platforms, and create incentives to accomplish this mission

3.0 SYSTEMS & FACILITIES MANAGEMENT



Systems and Facilities Management provides the oversight and assurance of readiness of the plant assets to execute all needed functions within the defined operating envelope. It includes the non-integrated smaller facilities; the larger, highly integrated facilities; and the neighboring, symbiotic-relationship facilities that share input/output streams. The topic includes maintenance and reliability and takes a local perspective, not including the supply network and globalization.

Subtopics included in **Systems and Facilities Management**:

- **Production Operations** – The execution of processes – individually and collectively – to produce the needed product. In most cases, production operations include a sequence of transformations and movement through multiple locations.
- **Management of Assets** – The oversight and assurance that the assets of the company and the enterprise are available and sufficient to meet the corporate objectives. This includes the optimization of asset procurement, retirement, liquidation, and all other aspects of asset management. In the smart manufacturing environment, assets will possess the capacity to self-evaluate their individual and integrated roles. This includes real-time evaluation of the state of operations including automation, and uses key-performance indicators.

- **<u>Situation Management (Unplanned and Unexpected)</u>** – The detection, evaluation, and understanding of existing conditions against the normal envelope for conduct of operations such that actions can be taken. In the event of deviations from the normal conduct of operations, the assessment includes the evaluation of options and the determination of best response. This topic includes the role of and the assurance of the capability of the human assets to respond properly, as well as automated systems and other technology.

3.1 Current State Assessment for Systems & Facilities Management

Current practice for management of process manufacturing systems and facilities shows a tension between reluctance to invest in more automation and retrofits for a facility that seems to be working pretty well. There are insufficient meaningful metrics for valuing different technologies or facility management techniques. There is insufficient technology and support for proactive, predictive operation. No one has demonstrated sufficient value during plant operations from molecular modeling or computational fluid dynamics requiring large computing clusters, so automation is generally limited to what can be done on a personal workstation. Technology upgrades are typically made on the basis of least risk, not best use.

3.1.1 Plant Operations

Many Manufacturing Execution Systems (MES) / shop floor functions are currently performed manually and use different systems that are not integrated. The data from these different systems cannot be integrated for wider use due to interoperability issues. However, it is recognized that automation and efficient operations dictates a systems view, so progress is being made with automation systems that utilize standards and provide advanced automation capabilities in the processing environment. The standards include S-88 for batch processing, which has yielded significant benefits (portability, reusability, reducing costs and increasing safety) and the Service Oriented Architecture (SOA), which assists in achieving easier integration of MES. Wireless applications are being deployed for non-critical monitoring, control, and other functions, but it is still not considered ready for critical sensing and control.

3.1.2 Management of Assets

Asset management systems enable understanding of the costs of all types of assets, resulting in the ability to control, plan, and avoid capital expenditures. Current practice is that assets do not have adequate monitoring due to technical capability limitations as well as the conflict between business objectives, such as service factors and energy use versus cost and profitability. As a result, indirect measurement often is the general practice. Alarm management systems that manage alarm response are fairly common. There is limited deployment in some companies of advanced networking protocols for smart assets and network based operation. Obsolescence generally drives replacement of assets, but the industry is moving toward predictive/preemptive maintenance practices.

3.1.3 Situation Management

Situation response in a process plant requires special skills, including an understanding of plant processes and their risks, various mitigation options, and the potential results of each. There may be many off-normal situations detected, and finding the root cause from multiple alarms is difficult. It is impossible to respond to each alarm, so currently the best response is usually based on knowledge and experience, not systems. Many companies conduct rigorous hazard and risk analysis, and have formal procedures to guide response and operators who are well trained in responding to abnormal situations. Dynamic models are often used by response teams in creating scenarios and in executing drills. Some companies are investing in knowledge capture and response systems (coupled with models) for optimized response, particularly in critical operations.

Current State Assessment for Systems & Facilities Management

Technical & Intellectual Barriers and/or Deficiencies	State of Art / Predominant Practice	Best Practices and Emerging Research
Systems & Facilities Management		
• Lack of integrated facilities • Aging workforce; hard to attract skilled workers for facility management • Problem getting capital improvements funded • Technology upgrades on basis of least risk, not best use; retrofits not usually done • Conflict/friction between continuous improvement, vs. "it's working well, don't touch it" • Insufficient meaningful metrics for valuing different technologies or facility management techniques • Awareness of value or availability of computing technology is not understood; deemed not worth the cost of use or maintenance. (e.g., real-time optimization) • Lack of technology and support for proactive, predictive operation	• Standalone facilities • Fixed cost pressures keep focus on maintaining current production • For real-time operations, automation limited to what can be done on a personal workstation; no one has demonstrated sufficient value during plant operations from molecular modeling or computational fluid dynamics requiring large computing clusters • Metrics missing; or not visible to those who need them • Computing power limited; flow sheet simulators and modeling done but limited in scope, because of complexity and computing requirements • Petrochemical industry using real-time operations and model predictive control (RTO/MPC). DuPont is not, because their processes are not as repetitive, more specialized. • Dow using some RTO and MPC, plus many batch plants for and specialty products	• Operations and process improvement done by different groups, avoiding conflict of missions (Eastman, Dow, Mitsubishi) • Controller performance monitoring used by DuPont; internally developed system • High-fidelity dynamic simulation being done by DuPont for strategy design and operator training • Nonlinear programming and mixed integer programming to optimize problems with thousands of variables. • Early event detection being done, based on statistical analysis, using McGregor's work • Use of ISA S88 standard for batch processing information; not new but still a best practice • Bayer and other companies using planning and scheduling optimization software • Single variable profile optimization (crystallization and batch reaction)
Production Operations		
• Predictive operation requires access to information and data, but the information needed is hindered by intellectual property barriers, e.g. information about equipment to improve a model • Many Manufacturing Execution Systems (MES) / shop floor functions are performed manually and use different systems that are not integrated. Automation and efficient operations dictates a systems view. • Data from different systems can not be integrated due to interoperability issues • Standard definition of data structures do not exist and the risks are	• Great progress is being made by adopting and deploying systems compatible with emerging standards • Companies that are using S88 for batch processing have reaped significant benefits (portability, reusability, reducing costs and increasing safety) • Service Oriented Architecture (SOA) is assisting in achieving easier integration of MES • Simulators and simulations are being used for operator training • Automation systems are utilizing standards and providing advanced automation capabilities in the proc-	• Adoption of S-95 for the integration of enterprise and control systems (still very generic) • Radio Frequency Identification (RFID) technology being used for locating assets • Dow has mapped its entire internal organization to S-95 • Human factors engineering being applied to develop human-machine interfaces and GUIs • All GUIs at Dow being implemented to one design regardless of supplier • Semantic models being utilized to

still too high for using standards that do exists because there is too much room for interpretation • Management of standards is inadequate: (a) lack of completeness, (b) too much interpretation • A lot of data is collected but not used (data graveyard). 95% not used? • Compartmentalization and sub-optimization limits achievement of total value operations • Skill requirement of operators is changing. The designed and executed total system is a continuous balance of humans and processes (requires training and a robust/effective human-machine interface) • The "characterization" of the complete production process (model) is not complete. Science based understanding is missing. Note: realism means having what is needed to perform the function. Molecular level modeling is not always required. • Models of processes and operations grow with advancement in demand and capability. Computational limitations come into play. • Lack of coordinated workflow within plant between organization within factory and equipment limits ability to optimize • Automation goals threatens the preservation of critical process knowledge • Systems are IT intensive. Managing production presents workforce capability and challenges	essing environment • Wireless applications for monitoring, control, and other functions being prototyped • Wireless being deployed for non-critical sensing. Still not considered ready for critical sensing and control • Remote process monitoring • Indirect measurement and projection to actual parameters	harmonize standards • Standard compliant system architecture enables modular systems to be integrated into systems. S-95 standards deployment is opening best of class options • Process safety and environmental management is being implemented and managed with separate metrics and tracking (harder to measure and manage) • Intelligent alarm management, event monitoring. and root cause analysis are being tied directly to process management (note: ISA work in progress for developing a standard for alarm management) • DuPont has a common system for process and control performance monitoring worldwide • Benefits analysis is being applied for the selection of candidates for optimization and advanced control • Closed-loop robust optimizers provide insight into circumstances and explain best options and trade-offs (the are examples across industry) • Collaborating models beginning to emerge: (a) configurable, (b) flexible, (c) open • Shell produces a single model of a factory and it operation before it is built and uses that model for process setup and optimization.
Management of Assets		
• Conflicting objectives : service factors conflict with profitability; energy KPIs conflict with profitability • Inefficient application of asset management systems • Assets do not have adequate monitoring due to lagging practice and capability limitations • Investment up front in the equipment and software needed for as-	• A lot of manual interaction based on skills and experience • Lots of equipment tied to sensor and control systems • Alarm management systems that manage alarm response • Obsolescence drives replacement of assets • Quantifying value through business	• Industry moving to predictive/preemptive maintenance • Predictive capability applies to all process assets (catalysts, etc.) not just equipment. Preemptive response includes "intelligent" changes to an operating environment (to avoid degradation and failure) • Early event detection and intelli-

set management is a hard sale-it does cost money • Indirect measurement often is inadequate and direct measurement is either not reasonable (cost prohibitive) or not now possible • Models and data are assets – they must be managed. Present management systems do not include this capability • The experience and knowledge from using the model is often as important as the results • Data collection is often not focused. “What is the data for” and “how will it be used” should precede the decision to collect • Real-time systems often lack the ability to validate the data before causing response • Trend is toward fewer sensors (due to cost). This trend is in conflict with the needs for good asset management	case analysis is being used in asset management decisions • Assets are different. There is no “standard formula” for determining the value of asset investment • Asset management systems enable understanding of costs of assets resulting in the ability to control, plan, and avoid capital expenditures. • Limited deployment of advanced networking protocols for smart assets and network based operation	gent response • Agent-based systems for prognostic operation seeing early deployment • New plants all talk to one network • In some edge-of-art examples, models are intelligent and connected across processes • Devices and equipment have self-assessment capabilities. Models do not, but will.
Situation Management (Unplanned and Unexpected)		
• Many off-normal situations detected with the impossibility of responding to all • Finding root cause from multiple alarms is difficult • Response is usually based on knowledge and experience, not systems • Training for abnormal response is difficult because the situations are hard to simulate • Continuous process data is of little value in situation response • Situation response requires special skills including understanding of risks, mitigation options, and potential result • Information needed for response is often not available • International boundaries and export controls limit remote response • System complexity inhibits evaluation of event/response automation	• Many companies conduct rigorous hazard and risk analysis • Rigorous procedures are in place for management of change • Rigorous procedures guide response and operators are well trained in responding to abnormal situations • Dynamic models are used by response teams in creating scenarios and in executing drills • More alarms and more problems than are necessary • Centralized operations and response (remote operations)	• Nuclear navy conduct of operations being applied in industry • Flight simulators provide a good model for training in the process industry • Optimization-based safe and efficient start-up and shut down of plant operations • Automated logbook reporting • Automated procedural operations • Centralized operations and response (remote operations) • Knowledge capture and response systems (coupled with models) for optimized response, particularly in critical operations • Near miss reporting

3.2 Vision for Systems & Facilities Management

Systems and facilities will be managed for optimum availability and performance. Continuous sensing and control, at the appropriate level based on the need, will assure safe, optimized performance with the realization of zero incidents and zero emissions. Models will accurately predict plant performance and will support automated and computer-assisted decision making for assurance of operation within the envelope for safety, environmental responsibility, and cost optimization.

Ubiquitous use of sensors of all types (not just process sensors) will enrich status models and enable more optimized facility operation, integrating environmental issues and market conditions into business decisions. The outcome of the models, sensors, and associated knowledge will be complete understanding of the system at any point in time, yielding meaningful metrics based around long-term technology and performance improvement instead of short-term financial gain. The realization of open, integrated systems for managing multiple facilities will remove the barriers to multi-plant operations and global companies. As a result, human and automated systems will have a better ability to manage the facility, and predict and analyze different options.

Notes and Attributes of the vision for Systems & Facilities Management:

The following attributes of the vision for Systems & Facilities Management were gathered from workshop participants. Letter codes indicate Industrial/Technological (I) and Intellectual/Academic (A) attributes. [Review is requested for confirmation of assignment.]

- Automated continuous improvement is routinely used. (I)
- Open, integrated systems for managing multiple facilities have removed the barriers to multi-plant operations and global companies. (A) (I)
- Seamless integration between plant's operation systems and the human operators. (A)(I)
- Model-driven plant operation; decisions driven by process models with continuous adaptation and improvement. (A)(I)
- Meaningful metrics based around long-term technology and performance improvement instead of short-term financial gain.(I)
- Continuous sensing of situation yields complete safety, optimized operation, avoidance of down-time or negative events.(A)(I)
- Large number of sensors of all types (not just process sensors) enrich status models and enable more optimized facility operation, and bring environmental issues, market conditions, etc. into business decisions.(A)(I)
- Outcome of models, sensors, etc. is complete understanding of the system at any point in time, yielding better ability to manage the facility, and predict and analyze different options.(A)(I)

3.2.1 Vision for Production Operations

Fundamental understanding and pervasive models will enable skilled people to optimize manufacturing processes for maximum profit in a safe, socially responsible, sustainable environment that automatically adapts to uncertainty and faults.

Process plants will be flexible, scalable, tolerant of uncertainty, and adaptive to change with dynamic response. Models will accurately represent plant operations, including the automatic capture and management of knowledge. This will enable all information needed for optimized operation to be "pushed" to the right place, at the right time to assure pro-active production and recommended decision alternatives. The information will be presented in a self-guiding and intuitive form making the right result obvious. Optimized processes will be based on open, integrated and flexible models wherein all operations are conducted within acceptable limits (time, quality. environmental, etc.). The result will be a plant that operates within all regulations and guidelines and is adaptable to change, enabling profitability with minimum human effort.

Notes and Attributes of the vision for Production Operations:

The following attributes of the vision for Production Operations were gathered from workshop participants. Letter codes indicate Industrial/Technological (I) and Intellectual/Academic (A) attributes. [Review is requested for confirmation of assignment.]

- Products made on demand, to spec, safely, on time, profitable, and sustainable (I)
- Economic topology well known with all factors included (results in the region of the optimum, confidence limits, sensitivity of the optimum, relationship to bounds, response factors known) (A)
- Processes are tolerant to uncertainty and the information available supports decisions that are tolerant to uncertainty. Degree of uncertainty drives investment in monitoring and control (A)(I)
- Fault-tolerant design (I)
- Flexible, scalable, adaptive to change with dynamic response (A)(I)
- The right plant that operates within all regulations and guidelines and is adaptable to change, enabling profitability with minimum human involvement (A)(I)
- Optimized processes based on open, integrated and flexible models wherein all operations are conducted within acceptable limits (time, quality. environmental, etc.) (A)(I)
- Chemical plants operate as a grid(I)
- Models accurately represent operations including the capture and management of knowledge (A)(I)
- All information needed for optimized operation is "pushed" to the right place, at the right time to assure pro-active production and included recommended decisions (I)
- The right information presented in a self-guiding and intuitive form making the right result obvious (A)(I)
- Configurable entities that may be modular, come together, to deliver best value products(A)(I)
- Best process options are directly transferred to industry for immediate solutions (A)

3.2.2 Vision for Management of Assets

Assets, many of them augmented with "smart" capabilities, will be managed according to their contribution and risk to assure the best total value, including profit, safety, sustainability, and social responsibility, employing the optimal degree of automation. Assets include people, systems, facilities and equipment, and knowledge – all of the elements that make the plant work.

Smart assets integrated with intelligent models of the process facility will be able to assess their operating environment and configure themselves for optimized operation. Devices, equipment and other assets will have self-assessment capabilities and predictive capabilities that allow detection of performance trends and requirement changes and "intelligent" coordinated adjustments to optimize total value and plant operation.

Notes and Attributes of the vision for Management of Assets:

The following attributes of the vision for Management of Assets were gathered from workshop participants. Letter codes indicate Industrial/Technological (I) and Intellectual/Academic (A) attributes. [Review is requested for confirmation of assignment.]

- Systems and people understand and coordinate to optimize total value. (A)
- Asset failure does not jeopardize people, profitability, or environment. (I)
- Widespread use of models to generate understanding and use that understanding to best manage knowledge, people, and assets. (A)(I)
- Smart assets configure themselves, based on models, for optimized operations.(A)(I)
- Plants and assets begin life at best possible state and are continuously improve (A)(I)
- Assets collect and provide a full systems view in an understandable manner(A)(I)
- Real-time, event-based asset management (I)

3.2.3 Vision for Situation Management (Unplanned and Unexpected)

Reliable and trustworthy systems quickly diagnose and resolve all abnormal situations with no compromise of safety. Prognostic systems predict failure so reliably that it never occurs, and resolution of pending situations is managed without interruption to critical processes.

Even when faced with unknown and undocumented events, assimilation and analysis of relevant accumulated operational data and recognition of patterns and behavior (including emergent behavior) will enable identification of both potential situations and best responses. If multiple sites are involved, collaborative technology between associated facilities will enable effective decision making and rapid marshalling of appropriate resources.

Notes and Attributes of the vision for Situation Management:

The following attributes of the vision for Situation Management were gathered from workshop participants. Letter codes indicate Industrial/Technological (I) and Intellectual/Academic (A) attributes. [Review is requested for confirmation of assignment.]

- Total failure yet still safe results (I)
- Provide relevant information quickly and clearly with decision support (I)
- Rapid identification of response necessities for appropriate marshalling of resources (I)
- Ready response for any abnormal situation (I)
- Collaborative technology enables effective decision making (A)(I)
- Preemptive practices in place to respond to imminent needs (I)
- Plan for every conceivable operation with training for needed response (A)(I)
- Assimilation of relevant data to identify best response to unknown and undocumented events (I)
- Recognition of patterns and behavior (including emergent behavior) to identify both potential situations and responses. Factors include the following: (A)(I)

  Anticipated response
  Unanticipated response
  No compromise of safety
  Links between abnormal situation and profitability
  Speed and confidence in reaction
  Speed and confidence in my actions. This response will be the best possible for
    - situations for which planning is possible
    - situations that are unusual that no planning is reasonable
    - combination of situations
    - self healing response systems

3.3 Issues and Solutions for Systems & Facilities Management

Issue SF-1: Lack of sufficient highly trained and skilled workforce
Issue SF-2: Inadequate mechanisms to ensure continuous improvement in operations
Issue SF-3: Lack of value proposition (including safety) for advanced modeling or other tools
Issue SF-4: Adoptions of new technology limited by meaningful shut-down economics, when cost of old technology (including capital recovery) is less than implementation of new technology (including capital recovery).

3.3.1 Issues and Solutions for Production Operations

Issue PO-1: Integration: Data, systems, operating functions and models are neither integrated nor fully coordinated

Issue PO-2: Standards: Current Standards are inadequate; they are not complete and leave room for too much interpretation.

Issue PO-3: Computational: Models of processes and operations grow with advancement in demand and capability. Computational limitations (hardware, algorithms, model formulation) come into play.

Issue PO-4: Modeling: Compartmentalization and sub-optimization (scope, accuracy, and consistency) limits achievement of total value operations

Issue PO-5: Training: Skill requirements of operators, engineers, and managers are changing. The designed and executed total system is a continuous balance of humans and processes (requires training and a robust/effective human-machine interface). Systems are IT intensive. Managing production presents workforce capability challenges

Issue PO-1: Integration: data, systems, operating functions and models are neither integrated nor fully coordinated	
Solution PO-1-1	Develop shared knowledge, information, data and model repositories that are compliant with existing standards and support sharing within a business reasonable environment
Solution PO-1-2	Use top-down decomposition of 'holistic optimization model' to develop components that avoid conflicting Key Performance Indicators (KPIs) and develop synergy among different applications and functions
Solution PO-1-3	Create systems that enable role-based visualization wherein problem components can be highlighted or hidden, resulting in the user view that is most appropriate for solution.
Solution PO-1-4	Apply the maximum appropriate level an of automation especially on the critical development path for integrated systems operation. Examples of critical path processes include on-line analysis, data communication, actuation and high frequency decision-making.

Issue PO-2: Standards: Current Standards are inadequate; they are not complete and leave room for too much interpretation	
Solution PO-2-1	Develop and apply common standards that facilitate communication among databases and hierarchical applications
Solution PO-2-2	Develop standards that enable cost effective development of modeling/optimization applications that resolve conflicting KPIs
Solution PO-2-3	Provide common systems and interfaces for interpretation/visualization of solutions for operators, engineers, and managers. Note: Dupont has a common user interface for all systems. This needs to be replicated and extended.
Solution PO-2-4	Provide tools that unify data and information systems to enable communication and decision making across functions (from the shop floor to the top floor)
Solution PO-2-5	Provide a systematic needs assessment and awareness of advances in technology across the process industry. In doing so, provide resolution to IP issues that inhibit cooperative research and technology deployment between industry and academia/research

Issue PO-3 Computational: Models of processes and operations grow with advancement in demand and capability. Computational limitations (hardware, algorithms, model formulation) come into play	
Solution PO-3-1	Update existing algorithms and develop new algorithms for control of both discrete and continuous processes.
Solution PO-3-2	Tailor new algorithms to take maximum advantage of parallel computing/multi-core processors (Moore's Law no longer applies)
Solution PO-3-3	Develop interfaces that enable better presentation of problems to modeling systems (including operator friendly interfaces) and that enable model evolution/learning to better solve the problems that are posed.
Solution PO-3-4	Provide unifying forums and tools to enable modelers, algorithm developers and IT staff to deliver integrated solutions through collaboration.
Solution PO-3-5	Develop an ability to assign or adapt the best modeling systems and optimizers to the task at hand. This could be done through the provision of an expert selection tool, based on requirements.

Issue PO-4 Modeling: Models need scope, accuracy, and consistency to achieve total value	
Solution PO-4-1	Adopt a holistic modeling approach (a "master model") that is capable of supporting a hierarchy of modeling needs through abstractions. The result will be the ability to provide the right level of detail, the right modeler, and the right data for each application in a structure. The hierarchy might be by perspective, level of the organization, or function e.g. control, RTL, or scheduling.
Solution PO-4-2	Provide open models for ease of formulation, configuration and collaboration
Solution PO-4-3	Provide consistent modeling platforms for portability of model development and evolution
Solution PO-4-4	Provide validation and verification of models for targeted applications with specified operating ranges and boundary conditions
Solution PO-4-5	Provide the modeling solutions to the users (operators, engineers, manage-

	ment) in a way that supports accurate, unambiguous interpretation and visualization.

Issue PO-5 Training: Skill requirements of operators, engineers, and managers are changing. The designed and executed total system is continuous balance of humans and processes (requires training and a robust/effective human-machine interface)	
Solution PO-5-1	Establish cultural awareness and expectations among organizational functions to overcome compartmentalization and assure alignment of the organization to accomplish the common, shared goal. Eliminate sub-optimization.
Solution PO-5-2	Provide a continuum of academic to industrial training, with feedback and updates, with strong interaction and exchange between communities (between students, faculty and industry)
Solution PO-5-3	Develop tools that provide a balance between the fundamental scientific base required for operation and the ease of use and presentation value required for useful application by all skill levels

3.3.2 Issues and Solutions for Management of Assets

Issue MA-1: The lack of a culture and system for creating, managing, valuing, and integrating models as enterprise assets that are maintained just like physical assets

Issue MA-2: Difficulty in collecting the right, validated data that supports the development of models and supports decision processing

Issue MA-3: Lack of predictive, coherent, decision making for maintaining and assuring reliability of assets and their operating environment including risk management

Issue MA-4: The lack of a systematic approach to capture the experience and knowledge of the workforce in a usable form

Issue MA-5: Lack of adequate training of the workforce to operate in a model-rich environment

Issue MA-1: The lack of a culture and system for creating, managing, valuing, and integrating models as enterprise assets that are maintained just like physical assets	
Solution MA-1-1	Provide automated model generation based on the function to be performed and the data that is needed/available, consistent across multiple applications
Solution MA-1-2	Provide the capability to efficiently perform business case analysis to support the investment in the creation, use and management of the model
Solution MA-1-3	Develop a management and technology structure for maintaining models as a corporate asset. This solution also would cut the cost of redundancy by making models available for multiple uses.

Issue MA-2: Difficulty in collecting the right, validated data that supports the development of models and supports decision processing	
Solution MA-2-1	Develop systematic methods for developing data models (plant semantic reference data models) to support business processes related to asset lifecycle management decisions

Solution MA-2-2	Assure the minimum set of data available, including proper redundancy, all based on a business case assessment. • If there is no defined use of the data, the data will not be collected. • All collected data will be managed as an asset. • Data will be collected and utilized at the point of use, and passed to the other layers of the structure as needed, in the form needed
Solution MA-2-3	Provide a shared data specification/architecture for access and management of data, information, and models. This specification may be based on semantic understanding and intelligent data/model management
Solution MA-2-4	Create standards for shared data across modeling applications
Solution MA-2-5	Provide data validation, cleansing, aggregation, and curation

Issue MA-3 Lack of predictive, coherent, decision making for maintaining and assuring reliability of assets and their operating environment including risk management	
Solution MA-3-1	Develop models and tools to track changes in process performance including the control systems performance
Solution MA-3-2	Develop knowledge based decision support systems for lifecycle asset management and collaborative decision-making that includes risk and uncertainty analysis. Apply mathematical tools such as hybrid systems optimization.
Solution MA-3-3	Utilize advanced data analysis tools in asset performance pattern/behavior recognition for predictive early-warning solutions

Issue MA-4 The lack of a systematic approach to capture the experience and knowledge of the workforce in a usable form	
Solution MA-4-1	Provide a knowledge management solution for asset management that allows operators, engineers, - all stakeholders to collaboratively enrich the knowledge base and extract value from collective knowledge set
Solution MA-4-2	Create expert process advisors that capture the knowledge and scientific basis for process operations and provide real-time advise for best actions
Solution MA-4-3	Provide a standard for knowledge capture and management for the process industry

Issue MA-5 Lack of adequate training of the workforce to operate in a model-rich environment	
Solution MA-5-1	Utilize visualization and simulation to train operators and engineers to understand the place of models in production operations and to utilize the models when and where needed
Solution MA-5-2	Provide real-time, point of use, training using emerging technologies. • Visualization at the point of use (often "hands free") • Real-time instruction as in telemedicine, enabling a remotely located expert to walk a less experienced/expert person through asset management analysis and solution

3.3.3 Issues and Solutions for Situation Management

Issue SM-1: Lack of intuitive technology-based tools to prepare the operator for response and to assure that the proper response is taken – available in the physical environment

Issue SM-2: The lack of information processing tools (software, methodologies, and procedures) that guide diagnosis and decision making,

Issue SM-3: The lack of a scenario based toolset to identify risks and prevent potential situations

Issue SM-4: The current culture in operations is predominantly reactive versus proactive for situation prevention and response. The organization is also not prepared to respond quickly

Issue SM-5: The loss of process operations knowledge/skills works against the ability to diagnose and respond. Factors include:

- Reliance on automation
- Attrition
- Pressures to reduce fixed cost
- Increase in scope of operator due to downsizing

Issue SM-1: Lack of intuitive technology-based tools to prepare the operator for response and to assure that the proper response is taken – available in the physical environment	
Solution SM-1-1	Provide technology (models, sensors, wireless, network architecture, security) that enables assets to self diagnose, publish state, self heal, or initiate a proper safe response.
Solution SM-1-2	Provide plant wide visualization of critical information. The system will pull process variable, do correlation and pattern recognition, and publish output.
Solution SM-1-3	Develop game-quality simulation and animation systems that enable hands-on, fully tactile, experience in a virtual environment directly transferable to the physical environment

Issue SM-2: The lack of information processing tools (software, methodologies, and procedures) that guide diagnosis and decision making	
Solution SM-2-1	Develop intelligent systems e.g. agent-based systems that are trained to monitor process and control functions and take the proper action to maintain in control operations
Solution SM-2-2	Provide useful (not legalistic or bureaucratic) procedures for critical operations available in step by step instructions, at the level needed by the operator. The level of detail in presentation might be guided by the experience and certification level of the operator
Solution SM-2-3	Create and deploy prognostic, intelligent systems for assured in control operations

Issue SM-3: The lack of a scenario based toolset to identify risks and prevent potential situations	
Solution SM-3-1	Provide virtual reality based experiences wherein various process scenarios can be reviewed with full analysis and ready awareness of the consequences of choices. Risk assessment will be included in the experience.
Solution SM-3-2	Provide scenario-based tools to enable the evaluation of responses to off-

	normal situations and determine the best courses of action. The evaluation will include risk assessment

Issue SM-4: The current culture in operations is predominantly reactive versus proactive for situation prevention and response. The organization is also not prepared to respond quickly	
Solution SM-4-1	Implement a culture of response readiness across the organization, and augment that cultural readiness with technology-based response tools
Solution SM-4-2	Implement a response planning program that involves all stakeholders and assure that the plan and the response permeates the organization
Solution SM-4-3	Develop prognostic systems and establish a proactive response culture

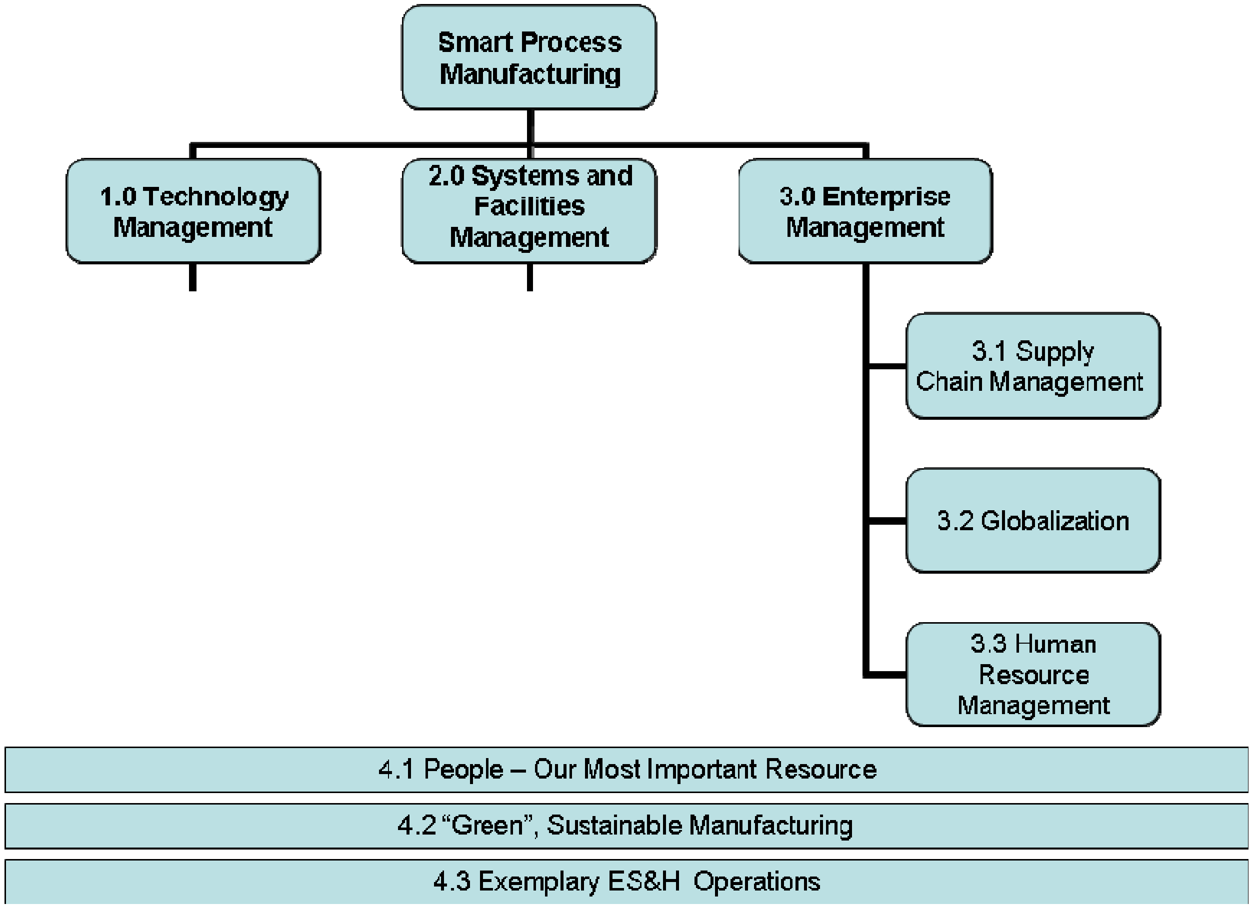
Issue SM-5: The loss of process operations knowledge/skills works against the ability to diagnose and respond	
Solution SM-5-1	Develop mentor/protégé programs to preserve critical skills
Solution SM-5-2	Implement a knowledge capture program to reduce the dependence on human skills
Solution SM-5-3	Utilize the knowledge capture program of 5.2 to continually train the staff and preserve core competencies

3.4 Top Priority Solutions for Systems & Facilities Management

Issue SM-1: Lack of intuitive technology-based tools to prevent situations and prepare the plant (people and assets) for proper response.	**Solution SM-1-1:** Provide technology (models, sensors, wireless, network architecture, security) that enables assets to self diagnose, publish state, self heal, or initiate a proper safe response.
Issue MA-1: The lack of a culture and system for creating, managing, valuing, and integrating models as enterprise assets that are maintained just like physical assets	**Solution MA-1-3:** Develop a management and technology structure for maintaining models as a corporate asset
Issue PO-1: Integration: data, systems, operating functions and models are partly manual, not integrated nor fully coordinated.	**Solution PO-1-2:** Use top-down decomposition of 'holistic optimization model' to develop components that avoid conflicting KPIs and develop synergy among collaborative applications and functions
Issue MA-2: Difficulty in collecting the right, validated data that supports the development of models and supports decision processing	**Solution MA-2-1:** Develop systematic methods for developing data model (plant semantic reference data models) to support business processes related to asset lifecycle management decisions
Issue PO-3: Computational: Models of processes and operations grow with advancement in demand and capability. Computational limitations (hardware, algorithms, model formulation) come into play.	**Solution PO-3-1 and PO-3-2:** (combined) Develop algorithms for large-scale hybrid (discrete and continuous) optimization, in particular take advantage of parallel computation/multi-core processors
Issue SM-5 & MA-4: (combined) *The loss of process operations knowledge/skills works	**Solution MA-4-1:** Provide a knowledge management solution that allows operators, engi-

against the ability to diagnose and respond; *The lack of a systematic approach to capture the experience and knowledge of the workforce in a usable form	neers, - all stakeholders to collaboratively enrich the knowledge base and extract value from the collective knowledge set
Issue PO-2: Standards: Current Standards are inadequate; they are not complete and leave room for too much interpretation.	**Solution PO-2-2:** Develop and apply model and data standards that stress overall benefits of modeling/optimization applications and resolve conflicting KPIs
Issue SM-1: Lack of intuitive technology-based tools to prevent situations and prepare the plant (people and assets) for proper response.	**Solution SM-1-2:** Provide plant wide visualization of critical information. The system will pull process variable, do correlation and pattern recognition, and publish output.
Issue MA-3: Lack of predictive, coherent, decision making for maintaining and assuring reliability of assets and their operating environment including risk management	**Solution MA-3-2:** Develop knowledge decision support systems for lifecycle asset management and collaborative decision-making that includes risk and uncertainty analysis.
Issue PO-4: Modeling: Models need scope, accuracy, and consistency to achieve total value	**Solution PO-4-1 and PO-4-4:** (combined) Implement a holistic modeling approach leading to evolution of consistent hierarchical approach for scope and fidelity for targeted optimization functions (control, RTO, scheduling) with methods to validate model accuracy and its limitations.
Issue MA-5: Lack of adequate training of the workforce to operate in a model-rich environment	**Solution MA-5-2:** Provide real-time, point of use, training using emerging technologies

4.0 ENTERPRISE MANAGEMENT



Enterprise Management takes an integrated view of all enterprise activities, including the integration of various functions within and across organizational boundaries. Hence, the span includes enterprise resource management within an organization and the management of the extended enterprise including the supply network, global relationships, etc. The perspective includes multiple plants working together, interaction between companies, and the integration and optimization of processing and business functions. Further, enterprise management includes business and strategic planning and positioning for corporate success.

Subtopics included in **Enterprise Management**:

- **Supply Chain Management** – The coordination and management of the supply base to ensure that the right materials and components come together at the right place, at the right time, and in such a way that a useful product results – 100% of the time. This includes the satisfaction of all business, technical, cultural, and regulatory obligations for every member of the supply network. This also encompasses not only the physical flow of materials, but the information flow across the supply chain. The long-held terminology of supply chain is giving way to the term "supply network" in recognition of the complexity of the interactions.

- **<u>Globalization</u>** – Includes all issues associated with decisions concerning location of operations, satisfaction of requirements for operation in the global community, balance of operations to assure that corporate goals are not compromised, and cultural issues such as language and traditions. In the ideal, enterprise management in a global environment embraces a balanced view of tradeoffs of all options for total value and long-term sustainability of the company. However, short-term profitability is often the most compelling consideration.
- **<u>Human Resource Management</u>** – Addresses the assurance of ready and sustained staffing to meet the needs today and in the future. This includes trends and staffing projections, education, training and life-long learning, work rules, and compensation. In a smart manufacturing environment, the people are a critical component in setting the strategies and assuring that those strategies are carried out in every function of the smart process enterprise.

4.1 Current State Assessment for Enterprise Management

Achieving smart manufacturing capabilities in the process manufacturing industry will require a much higher level of integration, flexibility, and adaptability in enterprise management than exists today. Although many business functions and many manufacturing functions have been integrated in large, complex software systems (ERP/ERM, PDM, etc.), there is still a lack of interoperability of business and technical functions across the enterprise. Furthermore, there is no direct connection between the manufacturing production goals and the larger business objectives of the enterprise. As the enterprise extends its relationship with supplier partners, there is a lack of consistent understanding of quality, safety and environmental standards across the supply chain, especially on a global basis. In addition, as companies become more closely integrated with their supply network and global partners, there is still a reluctance to share information freely and risk losing the company's intellectual property.

Another challenge is lost expertise as the industry's aging workforce has the potential of creating a loss of critical knowledge by attrition. Companies find it difficult to acquire needed skill sets and hard to attract skilled workers for some jobs, such as facility management. University curricula are not producing sufficient numbers of graduates with the needed practical and technical skills, so there is an ongoing dialogue on how U.S. universities should address this need.

4.1.1 Supply Chain Management

Although the network of suppliers has expanded greatly, reaching many hundreds of relationships for most large process manufacturing companies, there are still major challenges on achieving smoothly automated, just-in-time provision of needed resources. The different supply partners use different terminology and business systems (e.g. SAP, Oracle) and it is difficult to align and integrate the multiple database structures (even when nominally using the same major tools) so that automated planning and procurement can occur. The usual practice today is to develop custom models around the specific partners' business environments to get information flowing between manufacturing operations and the supply chain, and make that part of standard operations. There are a number of supply chain management tools to aid the process, but most tools are too locally focused and suboptimized, failing to deal with the complications as supplier relationships grow from cross-town to global in nature. It is difficult to address and understand uncertainty in the whole supply and demand chain, and to associate risk with the uncertainty. Furthermore, supplier and customer collaboration should broaden beyond basic business concerns to address energy and environmental issues such as carbon footprint of their products and processes.

4.1.2 Globalization

Globalization is the accepted normal mode of doing business, but forming global teams and partnerships is still a logistics challenge and funding issue. Going global makes everything more complicated, like dealing with time differences and resources in geographically remote locations, and determining how to work together and how to allocate tasks. The technology tools used need to be more globally adaptive, accommodate different languages and different toolsets at different locations, and able to integrate into different IT infrastructures.

In most companies, valued knowledge is not formally inventoried and certainly not universally shared. There is great concern over loss of developed intellectual property due to off-shore partnerships and facilities, and a variety of mitigating measures are being tried. When setting up off-shore facilities, the issue of portability of knowledge arises, determining how to build new capacity including the needed human perspectives, and whether to develop knowledge locally or import people. Most companies are moving to use of local expertise as much as possible. An additional globalization issue concerns the different interpretations on safety, health, economic biases, and their effect on plant management, the product life cycle.

4.1.3 Human Resource Management

The major human resource issues facing the process manufacturing industry are the graying workforce and loss of their technical knowledge and experience with attrition, and the lack of sufficiently qualified workers to replace them. The speed of change in industry's technology and operations has not been kept up with in academia; process manufacturing is still viewed as a fairly low-tech industry and not that attractive to many students. A number of studies have pointed out the issues and problems, but it has been difficult to translate that into actions that will assure an adequate supply of qualified graduates.

Internationally there is much greater competitiveness (in number and quality) in engineering and science graduates; fewer students go into engineering in the U.S. than in other countries, so fewer U.S. BS graduates possessing less technical knowledge are available to be hired by the U.S. process manufacturing industry. Furthermore, domestic students at both undergraduate and graduate levels typically lack language skills and international exposure needed for globalized operations. Fewer tenure-tracked faculty are teaching some needed practical topics like control and design, and universities are de-emphasizing these courses, which compounds the problems and leads to lack of faculty trained to teach control and design. There is growing dialogue between industry and academia on how to fit needed skills and technical expertise (e.g. in bio- or nano-technologies) into engineering curricula which are already deemed too large to fit into the typical 4-year university timeframe.

Meanwhile, in response to the lack of continuing education programs available in manufacturing, many organizations have internal "universities" for continuing education. Many companies are also making expanded use of available cooperative education and co-op programs.

Current State Assessment for Enterprise Management

Technical & Intellectual Barriers and Deficiencies	State of Art / Predominant Practice	Best Practices and Emerging Research
Enterprise Management		
• Lack of interoperability of all business and technical systems • Difficult to connect profitability objectives with process control objectives • Reluctance to share information between companies; fear of liability with respect to IP, environmental regulations, and export control • Aging workforce and loss of critical knowledge by attrition; difficult to acquire needed skill sets; needs to be addressed globally • Aging workforce; hard to attract skilled workers for some jobs, such as facility management • Stunted supply of qualified people from lack of government and industry support in recent years. Fewer folks trained leading to current shortage. • Lack of consistent quality, safety and environmental standards across supply chain, especially on global basis • Lack of tools to manage across extended enterprise. Problems have exceeded scope of current Supply Chain Management (SCM) tools. • Inability to appropriately account for and manage uncertainty; risk management and mitigation	• Some efforts toward standardized data structures; e.g. FIATECH ISO 15926; PDXI (Process Data eXchange Institute), CAPE (Computer-Aided Process Exchange) • Most suppliers moving into standard internet technology, abandoning proprietary networks • Oscillatory, economy-driven hiring/training situation; long lag between supply and demand of personnel	• Technical exchange among industry taking place in conferences and meetings, especially from more focused consortium activities • Growing trust relationships among companies to share data, benchmark processes (especially for society-benefiting processes like safety, environmental practices) • Center for Chemical Process Safety of AIChE working collaboratively for shared benefit • On global scene outside of U.S., some development of symbiotic communities of process industries • Dow, DuPont, and CH2MHill use planned skill growth programs and migrate staff through them using professional development plans; works best with internal education programs. • BP and MIT partnership to develop management skills needed; available training programs have good mix of industry and academics • ABET (Accreditation Board for Engineering and Technology) has now unified standards for educational programs of international universities; separate from foreign accreditation systems
Supply Chain Management		
• Lack of standardizing • Inability to predict demand reliably • No/few user-friendly modeling tools for value chain and supply chain • Gap between IT infrastructure and math models • Gap between enterprise level (planning level) and plant level • "Operationalizing" Available-To-Promise (ATP) at the planning and scheduling phase • Need broader perspective on Supply Chain (SC) (with sustainability perspective), concerning material flow overall on both upstream and downstream (i.e., by-products or wastes should be considered in supply chain)	• Different supply partners use different systems (SAP, Oracle, etc.) and in-house modeling done (MIMI-Aspen, etc.), but difficult to integrate into compatible IT infrastructure. • Develop custom model around the business environment, get information flow between operation and supply chain, Standard Operating Procedures (SOP) • Some vendors provide capacity planning tools, but most tools are suboptimal (too locally focused); e.g. may address promise to request to meet customer's requirement, but need to look broader impact on supply chain.	• Some mfg companies (e.g. DuPont, contact Jim Porter) put in production system which integrates all elements (SC, blueprint, small project) to run the assets optimally, with strategy dependent on specific applications, culture, etc. • Oil/gas industry leads in integrating large-scale optimization models in the SC for refining, transportation, delivering product; they are ahead of other process industries e.g. pharmaceuticals • IT perfecting use of Service Oriented Architecture (SOA), to integrate SOP with tools and different functions. Aim to model the business process and still make legacy

• Extend SC perspective to include knowledge as well as materials; shortage of strong models and computing power & applications to enable integration of IT. May be very good at a few points, but not globally optimized; information flow must be supported in both directions, between supplier and customer for collaboration. • Need symbiotic reuse (for zero emission) during life cycle/span of the materials, down to molecular level, by other processes (cradle-to-grave becomes cradle-to-another-cradle) • How to address and understand uncertainty in the whole supply and demand chain, and associate risk with the uncertainty • How to integrate R&D activities, address practical mfg issues, and mature the results into supply chain (process innovation, how to plug into supply chain, to avoid delay of new products into manufacturing) • Supplier and customer collaboration should broaden to address energy and environmental issues such as carbon footprint of their products and processes. • Need a big picture of the enterprise management • For diverse operations, need large scale optimization on global scale of SC • Within enterprise: need to integrate R&D, facility, materials, facility maintenance; mapping out the management for each branch within the integrated supply chain • DuPont has over 275 SCs at the enterprise level; there are inconsistencies among different SCs in regulations and laws that have huge impact, which limits people's ability to think about the SC. • Escalation of environmental regulation requirements (what can be measured vs regulated) as scientific and technical capabilities increase – e.g. former ppm requirements now become ppt (part per trillion) • Supply chain is global in nature, need to consider culture differences • Inventories, safety and waste issues, how to effectively manage inventories among supply partners.	• For large operations, many companies blueprint the asset base to view globally (age of plants, etc) to make decisions based on the big picture • At scheduling level, manual spreadsheets are commonly used; penetration of advanced tools is still limited • Tools are available to track things geographically and to customize dash-boards; more for batch industry	functions available. Gets around the interoperability issue; still requires standardization. • IBM in business of supplying servers to customers uses gaming theory in info exchange to obtain win-win results • IBM work with Statoil (Norway) on standardization of information integration framework • Use of SOA to allow people to use legacy procurement system (as a transition to the new system) • SOA collaborative forecasting based replenishment • BASF: EHS (sustainability), consider metrics for sustainability in SC, (New AIChE sustainability index/metrics) • In Process Systems Engineering (PSE), developing new models and algorithms to address multi-objectives. See Foundations of Computer-Aided Process Operations (FOCAPO) for emerging research

• Different terminology in SC, how to reconcile different names, how to automate the mapping between different languages • How to merge different data bases/structures automatically (many are manually currently) • How to extract information from different data/text systems and integrate with customer system • Mergers and acquisitions impact on SC		
Globalization		
• Different cultures, laws, local issues, lack of standards • Think globally but have to act locally, transition between these two perspectives • Intellectual Property (IP) protections, export controls • Issue of portability of knowledge, how to build new capacity including human perspectives; whether to develop knowledge locally or import people • Technology tools need to be more globally adaptive, and accommodate different tool sets at different locations; how to integrate different IT infrastructure. • Demand for different languages in tools • Pirating of developed IP lost due to off-shore partnerships and facilities • Cost components are variables; pricing and quality vary from place to place • Globalization is happening, so government agencies from different control points should interact • Different economic evaluations, royalties, tax incentives • Difficulties and risks of export of manufacturing technology (the "art" as well as science), some of it more in the heads of people than in technical approach. Risks: efficiency in training, loss of IP • For auto industry, in-flow (to US) is driven by productivity and labor	• Going global complicates mitigation of problems compared to centrally owned • Try to leverage the knowledge base when go global • Tendency to locate facilities close to the customer; more market sensitive, aids Just-In-Time inventory, site location considerations • Although expanding overseas in production facilities, and seeing profitable operation in U.S. and abroad, many companies limit scientific R&D to U.S. sites to retain and protect IP) • Uncertainty of operating overseas, all factors affect the decision on where manufacturing will go • Exchange rate plays a relatively small role. • Tendency to use expatriates (very expensive), maybe due to culture difference • Build local role is much cheaper, organization culture thing • US companies try to go locally as-soon-as-possible. • In recruitment, commonly send young employees to work overseas • Education may be global, but application is local	• CII (Construction Industry Institute) globalization project: globalized domestically with mobile office, or out of country; • Localization: have local people to run the business, (new term: "glocalization") • Have HQ-friendly person as a practical link from local to global • DuPont, DOW and IBM have increasing local management • Use of contextual sensitivity, building local support by transcending business function • Globalization becomes an integral part of education curricula. • DuPont developing alliance approach to work offshore, incentives to work together and stay together. Includes use of working contract, required corporate partner behavior, IP containment • DuPont uses "Black Boxing" of design and operations that are run by DuPont instead of other plant people. Protect internal core of valuable knowledge

• Challenges on both internal and external technical education, governmental restriction on visas, difficulty in bringing in trained work force • Huge consolidation, integrating back and forward in SC, but difficult to do • R& D: how to manage multi-country collaboration, how to get right people, right funding, no existing way to deal (e.g. DST-Dept of Science and Technology in India with NSF) not as effective today as before • “Cheap science” - fundamental research might be cheaper if overseas • IP retaining issue: current model on IP protection is not working, what is IP, who owns it? • Work inside or outside, need to use resources, how to select and use resources most effectively • Forming global teams is still a logistics challenge, funding issue. How to work together, time difference, geographically remote, how to allocate tasks • Engineering and design and R&D shared between different locations and times, but not in manufacturing • Cross-plant collaboration is difficult • Knowledge not inventoried and universally shared • Geo-politics, what happens if things turn around • Issues with long-term business sustainability and short-term profitability, job out-sourcing. • Globally different interpretation on safety, health, economic biases, effect on plant management, life cycle		
Human Resource Management		
• Graying workforce and technical knowledge • Internationally much greater competitiveness (number and quality) in engineering and science; fewer students go to engineering in U.S. than in other countries, so fewer U.S. BS	• Short-term fly-in of “expert” for fixing problems, who then leaves - results in no knowledge transfer • Expanded use of cooperative education and co-op program (DuPont)	• Require one semester abroad, oversea intern or co-op • Several VERY good studies (so it is not a lack of study/insight) : – National Academy of Sciences (NAS) -**The Engineer of 2020:**

graduates possessing less technical knowledge • Results of outsource may create IP and liability issues • Generational difference in work style/ethics, and learning style; manufacturing is viewed as low tech • Lack of continuing education program in manufacturing • Industry generally not aware of studies on human capital management by leading organizations although the studies are out there (but IBM has a big initiative on this) • Engineering & Construction Contracting Association (ECC - an affiliate of the American Institute of Chemical Engineers (AIChE)) did Workforce 20/20 survey on what/how teaching; gap between perception from academia and Industry • Management education/training at the enterprise level is more focused compared to technology workforce education at the "worker" level • DuPont: people are less willing to relocate as frequently compared to before • Lack of language skill; lack of international exposure at undergraduate and graduate level • Students: sense of provincialism • Discrepancy between academia and industry regarding future needs • Speed of change in industry is not kept up in academia • Many studies at high level and with recommendation, but no actual action plans; hard to convert/translate study to something implementable, gap between knowing what to do and doing what needs done • Faculty may not be willing to let	• Outsourcing of non-core technical competency • Companies not sufficiently using universities for technical continuous education • Use field programs to accelerate hiring, rotating and placement, working well in US, in transition to international • In core technology, consortium-based research is going on strongly • A lot of organizations have internal "universities" for continuous/ continuing education • In PSE, strong consortium in big research universities, but not in bio- or nano-technologies • Fewer tenure-tracked faculty are teaching control and design, and universities are de-emphasizing these courses, which compounds the problems and leads to lack of faculty trained to teach control and design • Companies have abdicated the deliver of the competency to vendors - like Aspen • Current practice in academia (hiring, rewards system) does not fit with the vision • Most faculty do not have industrial experience because it is not valued in academia • Many departments in academia have strong connection with industry advisory boards	**Visions of Engineering in the New Century, 2004**[3] – National Academy of Sciences (NAS) - **Educating the Engineer of 2020: Adapting Engineering Education to the New Century, 2005**[4] – NSF Human Capital Strategic Plan, March 2008[5] – IBM Expanding the Innovation Horizon - Global CEO Study 2006 (Executive Summary)[6] and **Introduction to the 2006 CEO Study**[7] – National Research Council (NRC) Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future (2007)[8] – Innovate America - Council on Competitiveness; National Innovation Initiative Summit and Report[9] • Timesharing of the technical personnel overseas, commodity services, (both locally and globally) • Selected outsourcing on non-IP • Some universities combining PSE with management element to increase students' attractiveness to industry • DuPont practices knowledge management, creating a knowledge base (mandatory "downloading" of knowledge), which reduces cost, helps globalization, develops people faster. More enterprise management oriented now, from culture change to a business process; could be done similarly for process management • Some use of multi-skilling - creation of more flexible workforce with more than one key skill (true skills as compared to education) • "Reverse Mentoring" - use of

[3] http://www.nap.edu/catalog.php?record_id=10999
[4] http://books.nap.edu/catalog.php?record_id=11338
[5] http://www.nsf.gov/pubs/2008/hcsp2008/nsf_humancapitalstrategicplan_0803.pdf
[6] http://www-07.ibm.com/in/university/relations/Pack_downloads/GE510-6258-00f.pdf
[7] http://www-03.ibm.com/industries/financialservices/doc/content/resource/thought/1594863103.html
[8] http://www.nap.edu/openbook.php?isbn=0309100399
[9] http://innovateamerica.org/files/InnovateAmerica_EXEC%20SUM_WITH%20RECS.pdf

graduate student go aboard for one semester • Fewer US students choose PSE when attending graduate school; although PSE students get better job options • IBM: how to generate or identify innovation • Tendency to define how to get things done then tell people or organizations to do it - this approach lacks the full engagement of all the organizations		younger employees to mentor older employees regarding generational work/social perspectives

4.2 VISION FOR ENTERPRISE MANAGEMENT

Enterprise management tools, cost-effective technologies and cross-industry standard practices in the future will enable U.S. manufacturing companies to successfully collaborate and compete in the global economy.

Beneficial technologies and productivity improvements will spread across global industry via the development of industry-wide standards. Interoperability of systems will enable use of the complete set of plant and enterprise data in decision making. ES&H concerns will be effectively addressed by collective cross-industry practices on a global basis, enabled by the better tools and technologies that comply with industry standards. Cybersecurity technology will automatically provide protection of Intellectual Property, and liability and trust issues will be resolved to the extent that cross-industry relationships are encouraged. The cost-effective, flexible and adaptive operation that results from these improved technologies will assure U.S. competitiveness in the global market.

NOTE: In the following sections, these codes are used: A = Academic E = Enterprise perspective; G = Globalization; HR = Human resources Management; I = Industrial; P = People; SC = Supply Chain. The (I) and (A) attributes were assigned after the workshop as part of note “clean-up”. Review is requested for confirmation of assignment.

Notes and Attributes of the vision for Enterprise Management:

The following attributes of the vision for Enterprise Management were gathered from workshop participants.

- Interoperability of systems enables use of complete set of plant data in decision making. (E) (I) (A)
- Chemical engineering and other process manufacturing disciplines are viewed as attractive fields and career options for students. (HR, P) (A)
- ES&H concerns are effectively addressed by collective cross-industry practices on a global basis, enabled by better tools and technologies. (G) (I)
- U.S. workforce can compete with any global competitor. (G, HR) (I) (A)
- Open sharing and collaboration on common goals (sustainability, safety, environment, health). (SC, G) (I)
- Liability issues resolved to the extent that cross-industry relationships are encouraged. (SC) (I)
- Beneficial technologies and productivity improvements spread across global industry via development of industry-wide standards. (G) (I)
- Competitiveness comes from flexibility and cost-effective use of technologies. (E) (I)

4.2.1 Vision for Supply Chain Management

The supply chain will be a cyber-enabled ecosystem that is fully integrated, optimized, flexible, agile, cost-effective, reliable and sustainable. It will ensure the right resources reach the right people when needed. The supply chain will be managed at multiple levels (strategic, tactical, operational, and practical) through the use of large-scale, multi-level (time and space) optimization models, where uncertainty is treated through adaptable, self-learning, self-correcting, self-maintaining robust solutions. It will employ fully-defined metrics to support continuous improvement in sustainability, safety, security, environment, and health across the enterprise.

Partners in the supply chain will openly collaborate, optimally allocate their tasks, and share their information and systems to meet common goals on sustainability, safety, environment, health as well as profitable operation. With all these improvements, the partners will progress to become a supply ecosystem which supports safe, optimized operations and mass-customization of product to suit the customer's changing needs.
Note: The traditional term supply chain is gradually being supplanted by supply network or supply eco-system.

Notes and Attributes of the vision for Supply Chain Management:

The following attributes of the vision for Supply Chain Management were gathered from workshop participants.

- Open sharing and collaboration on common goals (sustainability, safety, environment, health). (SC, G) (I)
- Liability issues resolved to the extent that cross-industry relationships are encouraged. (SC) (I)
- Fully integrated, optimized and flexible SC that is cost effective and sustainable (A) (I)
- Decision making with awareness of uncertainty (A) (I)
- Large-scale, multi-level (time and space) models supporting both daily operation and strategic decision (A) (I)
- Ensure right resource reach right people when they need it in a reliable way (I)
- Manage at multiple levels (strategic, tactical, operational, and practical) (I)
- Fully defined metrics for sustainability to be integrated into decision making processes (A) (I)
- Adaptable/agile, self-learning, self-correcting, self-maintaining robust solution (A) (I)
- Identify tasks and who to best perform, for what reason (I)
- Progress from SC to supply network to supply ecosystem which support mass-customization (A) (I)

[Key future views for the chemical industry may be found in Office of Industrial Technologies (OIT) Industry of the future *New Process Chemistry Technology Roadmap* http://www.chemicalvision2020.org/pdfs/new_chemistry_roadmap.pdf]

4.2.2 Vision for Globalization

The smart process manufacturing company of the future will be a cyber-enabled enterprise that focuses on value-creation, innovation, and sustainability across the enterprise, and competes effectively and efficiently using a diverse and borderless workforce, both globally and locally. Work practices will be anchored on achieving high levels of ES&H as well as producg quality, enhanced decision-making, and reduced liability, as a result of accessibility and connectivity to both global and local information, knowledge, experience, and wisdom.

Compliance with industry-wide standards will yield beneficial technologies and tools and productivity improvements that will spread across the global industry. Securely sharing information and collaborating between partners, the U.S. companies and workforce will be able to successfully compete in the global market.

Notes and Attributes of the vision for Globalization:

The following attributes of the vision for Globalization were gathered from workshop participants.

- ES&H concerns are effectively addressed by collective cross-industry practices on a global basis, enabled by better tools and technologies. (G) (I)
- U.S. workforce can compete with any global competitor. (G, HR) (A) (I)
- Open sharing and collaboration on common goals (sustainability, safety, environment, health). (SC, G) (I)
- Liability issues resolved to the extent that cross-industry relationships are encouraged. (SC) (I)
- Beneficial technologies and productivity improvements spread across global industry via development of industry-wide standards. (G) (A) (I)
- Leverage local expertise worldwide (I)
- Cyber-infrastructure support globalization (A) (I)
- Visibility of value creation across the enterprise (A) (I)
- Capitalizing on diversity of the global state for the enterprise management, decision making and innovation (I)

4.2.3 Vision for Human Resource Management

Global, virtual teaming and knowledge management deliver continued improvement in enterprise value creation and human resource renewal. Industry and academia are aligned on competency, capability, and the need for international experience. Smart manufacturing offers an attractive career path for chemical engineers and other process manufacturing specialists.

Graduates with needed specialties will regularly flow from the educational “pipeline”, and continuing education programs will assure continued refresh of skills and knowledge for successful competition in the global economy (“K-to-Gray” education).

Notes and Attributes of the vision for Human Resource Management:

The following attributes of the vision for Human Resource Management were gathered from workshop participants.

- Chemical engineering and other process manufacturing disciplines are viewed as attractive fields and career options for students. (HR, P) (A)
- U.S. workforce can compete with any global competitor. (G, HR) (A) (I)
- Industry and academia are aligned in terms of needs and goals and delivery of education (A) (I)
- Strengthen the pipelines; fully extended and continuing education (K-gray) (A)
- Fully realized conversion of data to information to knowledge to experience to wisdom (A) (I)
- Virtual teaming is pervasive and global (A) (I)
- International exposure in education is essential and routine (A) (I)

4.3 Issues and Solutions for Enterprise Management

Issue E-1: Lack of culture and toolset for integrated thinking based on information from across the plant and across industries

Issue E-2: Inability to sufficiently quantify and mitigate risk and uncertainty

Issue E-3: Lack of continuous supply of workforce with needed skills, (technical and business)

Issue E-4: Inability to share and integrate data among supply partners; data integration, currency, validity

4.3.1 Issues and Solutions for Supply Chain Management

Issue SC-1: There is a gap between IT infrastructure and math models due to lack of standardization and different terminology in SC. There is a need to know how to reconcile different names, how to automate the mapping different language, how to merge different data base/structure automatically (many are manually currently)

Issue SC-2: Need models to capture the big picture for enterprise management. There is a gap between enterprise level (planning level) and plant level (scheduling); Available-To-Promise (ATP) from the planning level needs to be operationalized at the scheduling level.

Issue SC-3: Need to be able to assess and model uncertainty in the entire supply chain (demand/supply disruption) and manage associated risk for any set of KPIs (key performance indicators)

Issue SC-4: Integrate the energy use associated with material flow in supply chain management, and evaluate the Carbon footprint, reuse (for zero emission), life cycle/span of the molecule (cradle to cradle)

Issue SC-5: Within enterprise: R&D, process innovation, new product introduction, facility, material, maintain facility; mapping out the management of supply chain for each branch within the integrated SC (supply chain)

Additional Issues:

- No /few user friendly modeling on value chain and supply chain
- Different perspective on Supply chain (sustainability), material flow over all on both up stream and down stream (by-products or wastes should be considered in supply chain)
- Expend supply chain to include both knowledge, model vs computing power (applicability) work it, integration, may be very good at a few point, but not globally, (sub-optimization), information flow in both direction, between supplier and customer, or collaboration.
- IBM on server supply to customer requires the information sharing to obtain win-win, gaming,
- R&D activities affect supply chain (process innovation how to plug into supply chain, delay of new products into manufacturing)
- DuPont has over 275 SCs, at the enterprise level, there are inconsistencies among different SCs; regulations and laws are limited control but have huge impact, which limits people ability to think about the SC.
- Limitation of science (technology) on regulation (what can be measured vs regulated)
- Supply chain is global in nature, need to consider culture difference
- Inventories, safety issue, how to effective manage inventories.
- How to extra information from different data/text and integrate with its own system
- Mergers and acquisitions impact on SC

Issue SC-1: There is a gap between IT infrastructure and math models due to lack of standardization and different terminology in SC. There is a need to know how to reconcile different names, how to automate the mapping different language, how to merge different data base/structure automatically (many are manually currently)	
Solution SC-1-1	Develop large-scale information retrieval techniques for rationalizing unstructured data and performing feature extraction in SC databases (combine 1&2 because of similarity)
Solution SC-1-2	Use self-learning and adaptive techniques to evolve standards (meta models and/or semantic models) and to map process components to meta/semantic models (combine 1&2 because of similarity)
Solution SC-1-3	Develop new theories for automatically performing mapping and aggregation of objects in SC management (e.g. extends social choice theory to aggregate across preferences)
Solution SC-1-4	Develop standards and APIs for mathematical models of different complexity so that supply chain can be made more agile
Solution SC-1-5	Apply service-oriented architecture so that supply chains can be synthesized,

	reconfigured and recomposed

Issue SC-2: Need models to capture the big picture for enterprise management. There is a gap between enterprise level (planning level) and plant level (scheduling); Available-To-Promise (ATP) from the planning level needs to be operationalized at the scheduling level.	
Solution SC-2-1	Develop methods to integrate planning and scheduling by identifying key manufacturing constraints that need to be accounted for in planning. (combine 1&2 because of similarity)
Solution SC-2-2	Develop algorithm and framework for multi-objectives (e.g., due date vs capacity utilization), multi-time period. Multi-scale approaches for integrating enterprise and plant levels (combine 1&2 because of similarity)
Solution SC-2-3	Exploit multi-core and multi-processor architectures and hardware in algorithm development

Issue SC-3: Need to be able to assess and model uncertainty in the entire supply chain (demand/supply disruption) and manage associated risk for any set of KPIs (key performance indicators)	
Solution SC-3-1	Investigate how structured uncertainty (disruption) and parametric uncertainty can be treated to address KPI's (e.g., profit, sustainability, carbon footprint) (combine with SC-4-1 because of similarity)
Solution SC-3-2	Determine how to quantify risk in each sub-process (e.g., weighting and how it affects overall performance in manufacturing.
Solution SC-3-3	Disruption planning algorithms need development along with suitable computing schemes (e.g., parallel computing)
Solution SC-3-4	Develop approaches for estimating and analyzing tails of distributions to deal with abnormal events e.., (high demand volatility and weather events)
Solution SC-3-5	Investigate use of graph theoretic concepts such as belief networks to model risk events in SCM (e.g., joint probability distributions)

Issue SC-4: integrate the energy use associated with material flow in supply chain management, and evaluate the Carbon footprint, reuse (for zero emission), life cycle/span of the molecule (cradle to cradle)	
Solution SC-4-1	Model energy use in supply chain and evaluate the carbon footprint (combine with SC-3-1 because of similarity)
Solution SC-4-2	Determine optimal abatement strategies for carbon footprint
Solution SC-4-3	See SC-3 solutions

Issue SC-5: Within enterprise: R&D, process innovation, new product introduction, facility, material, maintain facility; mapping out the management of supply chain for each branch within the integrated SC (supply chain)	
Solution SC-5-1	Need agile supply chain ...see SC-1 solutions
Solution SC-5-2	R&D process innovation and new product introduction are like supply chain disruptions see SC-3 solutions

\4.3.2 Issues and Solutions for Globalization

Issue GL-1: Contextual Diversity, which is composed of social, cultural, political, legal, fiscal, and economic issues at a local level, combined with a lack of standards and interpretations of intellectual property

Issue GL-2: Global/local synergy, which addresses the need for awareness and understanding, at a local level, of prevalent mental paradigms; of the different interpretations on ES&H issues; of special language requirements; of cost and pricing variability; and integration of technology tools.

Issue GL-3: Multinational, multi-stakeholder, and multidisciplinary integration, which includes cross-country, cross-industry, cross-plant, and cross-team global collaboration.

Issue GL-4: Resource optimization in terms of what needs to be done, how it is best accomplished, where should it best be done, and what resources should be used.

Issue GL-5: Technical education and training, both internal and external to the enterprise, which currently faces inhibitors, obstacles, and barriers for effectiveness and efficiency, such as government restrictions of mobility of the workforce.

The following notes were used to generate above "top 5" Issues on Globalization:

Notes for Issue GL-1:

- Culture, laws, local issues, lack of standards
- IP protections, export controls,
- Pirating (developed IP lost due to capitalization?)
- Economic evaluation are different, royalty, tax incentives
- Loss of IP
- IP retaining issue: current model on IP protection is not working, what is IP, who owns it?
- Knowledge not invented universally
- Geo-politics, what happens if things turn around

Notes for Issue GL-2:

- Think globally but have to act locally, transition between these two perspectives
- Technology tools need to be more globally, different tool sets at different location, how to integrate different IT infrastructure.
- Demand on different language in tools
- Cost components are variables. Localization (pricing and quality various from place to place)
- Globally different interpretation on safety, health, economic biases, effect on manage plant, life cycle

Notes for Issue GL-3:

- Globalization is happening, government agencies from different control should interact
- Huge consolidation, integrating back and forward in Supply Chain, but difficult to
- R& D: how to manage multi-country collaboration, how to get right people, right funding, no existing way to deal (DST in India with NSF not as effective today as before)

- IBM: forming global teams is still a challenge, funding issue? How to work together, time difference, geographically? Allocation of tasks
- Engineering and design and R&D shared between different location and time, but not in manuf.
- Cross plant collaboration is difficult
- How best to partition the problems so that different sites can work out the sub-solution and integrate back.

Notes for Issue GL-4:

- "cheap science" - fundamental research might be cheaper if overseas
- Work inside or outside, need to use resources, how to select and use in the way effectively
- Long-term business sustainability and short-term profitability, job out-sourcing. Issues here?
- Export manufacturing technology (art compared to science), more in the people than in approach,

Notes for Issue GL-5:

- Efficiency in training,
- Internal and external technical education, governmental restriction on visas, on bringing in trained work force

Issue GL-1: Contextual Diversity, which is composed of social, cultural, political, legal, fiscal, and economic issues at a local level, combined with a lack of standards and interpretations of intellectual property.	
Solution GL-1-1	The Problem: There are too many specific issues at a local level that create a dynamically changing environment, where universality is low and relativity is high. The Solution: Development of local partnerships, with an intent of building long-term relationships and growing local capability.
Solution GL-1-2	The Problem: There is a lack of standards, best practices, common processes, and tool sets. The Solution: Creation of a core set of standards, best practices, common processes, and tool sets, which can be applied universally, and which contain enough levels of flexibility to adapt to specific local contexts.
Solution GL-1-3	The Problem: Intellectual Property (IP), from a global perspective, falls within a range from closely guarded and not shared, to openly shared and borrowed, not necessarily in a legal way. The Solution: Re-assessment of the business value of IP to the enterprise to find an optimal balance between close and open approaches to IP development, application, and sharing on global.
Solution GL-1-4	The Problem: There are significant inhibitors, obstacles, and barriers to be aware of, to understand, and to able to interact, with social, cultural, political, legal, fiscal, and economic issues at a local level. The Solution: Creation of enablers, obstacle-removers, and barrier-breakers through the solutions in GL 1-1 through GL 1-3, and also, by not making assumptions based on limited regional experiences, perceptions, stereotypes, and prejudgments.

Issue GL-2: Global/local synergy, which addresses the need for awareness and understanding, at a local level, of prevalent mental paradigms; of the different interpretations on ES&H issues; of special language requirements; of cost and pricing variability; and integration of technology tools.	
Solution GL-2-1	The Problem: The variability in the interpretation and application of values, goals, and approaches to ES&H creates different levels of risk, and increases the potential for incidents. The Solution: Definition of a core set of ES&H best practices to raise the living standards at a global scale.
Solution GL-2-2	The Problem: There is a high level of variability in cost and pricing at the local/regional levels. The Solution: Development of better costing models and of better pricing models that incorporate local input more formally and explicitly, and that establish economic assumptions, which are more reflective of local context.
Solution GL-2-3	The Problem: There is a high level of diversity in the use of technology tools at a local level, which are based on preferences stemming from local social, cultural, political, legal, fiscal, and economic issues. The Solution: Creation of an integrated core set of processes and tools, aligned with the business enterprise, which can be applied universally, and which contain enough levels of flexibility to adapt to specific local contexts.

Issue GL-3 Multinational, multi-stakeholder, and multidisciplinary integration, which includes cross-country, cross-industry, cross-plant, and cross-team global collaboration.	
Solution GL-3-1	The Problem: Global collaboration is affected by the current state of world affairs. The Solution: Development of a framework for international collaboration that balances working directly or through intermediaries, and that is flexible enough to adapt to unforeseen developments.
Solution GL-3-2	The Problem: The lack of sharing of best practices and lessons learned across different industry sectors. The Solution: Development of forums, mechanisms, and functional enablers that allow normalization, standardization, communication, validation, and collaboration between and among industry sectors. (External) combine with 1-2 and 3-3
Solution GL-3-3	The Problem: The lack of sharing of best practices and lessons learned across different manufacturing facilities within an enterprise. The Solution: Development of forums, mechanisms, and functional enablers that allow normalization, standardization, communication, validation, and collaboration between and among manufacturing facilities. (Internal)

Issue GL-4 Resource optimization in terms of what needs to be done, how it is best accomplished, where should it best be done, and what resources should be used.	
Solution GL-4-1	The Problem: Resource optimization models (materials) need to reconcile a global perspective with the reality at a local level. The Solution: Development of economic models for global acquisition and distribution of material resources for optimal manufacturing efficiency.

Solution GL-4-2	The Problem: Resource optimization models (workforce) need to reconcile a global perspective with the reality at a local level. The Solution: Development of a framework and practices for a global work-force that can be deployed locally for optimal manufacturing efficiency.
Solution GL-4-3	The Problem: Resource optimization models (processes and technologies) need to reconcile a global perspective with the reality at a local level. The Solution: Development of a conceptual framework and implementation roadmap for the deployment of standard core processes and technologies locally for optimal manufacturing efficiency. Combine 4-1 ~ 4-3

Issue GL-5 Technical education and training, both internal and external to the enterprise, which currently faces inhibitors, obstacles, and barriers for effectiveness and efficiency, such as government restrictions of mobility of the workforce.	
Solution GL-5-1	The Problem: Technical education and training does not reflect the global reality. The Solution: Re-assessment of current approaches to what is taught, how it is taught, with what it is taught, and where it is taught, and development of curricula, pedagogical approaches, and educational resources that reflect the global reality. Combine 5-1 with 5-2
Solution GL-5-2	The Problem: Technical education and training is fragmented vertically and horizontally, both internally and externally to the enterprise. The Solution: Development of a cohesive, vertically and horizontally integrated education and training programs, optimizing the balance between internal and external delivery. Could be combined with HR
Solution GL-5-3	The Problem: Lack of recognition and reciprocity of credentials (e.g., knowledge, degrees, certification) for technical personnel restricts mobility. The Solution: Development of a "Universal Credential" system that allows high levels of mobility for smart manufacturing technical personnel.

4.3.3 Issues and Solutions for Human Resource Management

Issue HR-1: Graying workforce and technical knowledge: loss of experience and accumulated knowledge and lack of development of next generation

Issue HR-2: Discrepancy between academia and industry on future competence, capability and experience needs

Issue HR-3: High level studies on future HR needs have not produced any implementable action plan to eliminate the gap between Knowing and Doing

Issue HR-4: Executive programs address business management, but not technology workforce continuing education

Issue HR-5: no #5 was developed

Additional Notes on Issues:

- Lack of language skill; lack of international exposure at undergraduate and graduate level; Speed of change in Indus. Is not kept up in acad. (ECC work force 20/20, survey: what/how teaching,) gap between perception from academia and industry
- Internationally much greater competitiveness (number and quality) in engineering and science, number of students go to engineering in US vs. other country, US BS graduates possess less technical knowledge)
- Results of outsource may create IP and liability issues
- Generational difference in work style/ethics, and learning style, manufacturing style; manufacturing is viewed as low tech.
- Tendency to define how to get things done and tell people do as (lack the full engagement of all the people)
- Industry are generally not aware of studies on Human capital management by leading organizations although the studies are out there (but IBM has a big initiative on this)
- DuPont: people are less willing to relocate as frequently compared to before
- Students: sense of provincialism
- Faculty may not willing to let graduate student go aboard for one semester
- Fewer US students choose PSE when attend graduate school; although PSE students get better job markets
- IBM: how generate or identify innovation

Group Discussion: Should government provide solutions or is it up to the industry /academic leaders to make the change? It seems that the ones who need to use the tools should drive the change.

Key organizations identified by the team for researching, developing, demonstrating, and implementing HR and other issues:

- Construction Industry Institute (CII) - best practices (demonstration and implementation)
- FIATECH - standards (development and demonstration)
- National Science Foundation (NSF) - technology development (R&D)

Issue HR-1: Graying workforce and technical knowledge: loss of experience and accumulated knowledge and lack of development of next generation	
Solution HR-1-1	Broader implementation of knowledge capture processes and practices.
Solution HR-1-2	Early career development programs designed to accelerate new employee’s understanding and capabilities
Solution HR-1-3	Incentives to extend careers for current employees
Solution HR-1-4	Improve the attractiveness of the career path in manufacturing to get more people

Issue HR-2: Discrepancy between academia and industry on future competence, capability and experience needs	
Solution HR-2-1	Cross-fertilize knowledge and experience by exchange program
Solution HR-2-2	Industry will actively participate in the advisory councils in academia on research and curriculum development
Solution HR-2-3	Develop national and International academic-industry cooperative field

	programs
Solution HR-2-4	Develop Masters of engineering program for manufacturing in collaboration with industry

Issue HR-3: High level studies on future HR needs have not produced any implementable action plan to eliminate the gap between Knowing and Doing	
Solution HR-3-1	Broad collaborative involvement of government, labor, industry, and academia to convert current understanding of issues into a prioritized roadmap

Issue HR-4: Executive programs address business management, but not technology workforce continuing education	
Solution HR-4-1	Industry leaders should have manufacturing experience
Solution HR-4-2	Enhanced emphasis is required on continuing education on industry specific technologies as part of job profiles; Professional organizations (ACS, AIChE) who would develop these courses from active collaborative initiatives among industrial thought leaders and academia (combine solutions from GL to HR)
Solution HR-4-3	Industry to determine and advocate to academia on effective, needful and beneficial technology / manufacturing knowledge for developing continuing education program

4.4 Top Priority Solutions for Enterprise Management

Issue SC-1: There is a gap between IT infrastructure and math models due to lack of standardization and different terminology in SC. There is a need to know how to reconcile different names, how to automate the mapping different language, how to merge different data base/structure automatically (many are manually currently)	**Solution SC-1-1:** Develop large-scale information retrieval techniques for rationalizing unstructured data and performing feature extraction in SC databases ...AND... SC-1-2 Use self-learning and adaptive techniques to evolve standards (meta models and/or semantic models) and to map process components to meta/semantic models
Issue SC-2: Need models to capture the big picture for enterprise management. There is a gap between enterprise level (planning level) and plant level (scheduling); ATP from the planning level needs to be operationalized at the scheduling level.	**Solution SC-2-1 and SC-2-2** (combined): *Develop methods to integrate planning and scheduling by identifying key manufacturing constraints that need to be accounted for in planning; and *Develop algorithm and framework for multi-objectives (e.g., due date vs capacity utilization), multi-time period. Multi-scale approaches for integrating enterprise and plant levels
Issue SC-3 and SC-4 (combined): *Need to be able to assess and model uncertainty in the entire supply chain (demand/supply disruption) and manage associated risk for any set of KPIs (key performance indicators); and *Integrate the energy use associated with ma-	**Solution SC-3-1and SC4-1** (combined): *Investigate how structured uncertainty (disruption) and parametric uncertainty can be treated to address KPI's (e.g., profit, sustainability, carbon footprint); and *Model energy use in supply chain and evaluate the carbon footprint

terial flow in supply chain management, and evaluate the Carbon footprint, reuse (for zero emission), life cycle/span of the molecule (cradle to cradle)	
Issue GL-1: Contextual Diversity, which is composed of social, cultural, political, legal, fiscal, and economic issues at a local level, combined with a lack of standards and interpretations of intellectual property.	**Solution GL-1-2:** Creation of a core set of standards, best practices, common processes, and tool sets, which can be applied universally, and which contain enough levels of flexibility to adapt to specific local contexts.
Issue GL-2: Global/local synergy, which addresses the need for awareness and understanding, at a local level, of prevalent mental paradigms; of the different interpretations on ES&H issues; of special language requirements; of cost and pricing variability; and integration of technology tools.	**Solution GL-2-2:** Development of better costing models and of better pricing models that incorporate local input more formally and explicitly, and that establish economic assumptions, which are more reflective of local context.
Issue GL-3: *Multinational, multi-stakeholder, and multidisciplinary integration, which includes cross-country, cross-industry, cross-plant, and cross-team global collaboration.	**Solution GL-3-2, and GL-3-3** (combined): *Development of forums, mechanisms, and functional enablers that allow normalization, standardization, communication, validation, and collaboration between and among industry sectors. (External); and *Development of forums, mechanisms, and functional enablers that allow normalization, standardization, communication, validation, and collaboration between and among manufacturing facilities. (Internal)
Issue GL-4 Resource optimization in terms of what needs to be done, how it is best accomplished, where should it best be done, and what resources should be used.	**Solution GL-4-1, GL-4-2, and GL-4-3** (combined) *Development of economic models for global acquisition and distribution of material resources for optimal manufacturing efficiency. *Development of a framework and practices for a global workforce that can be deployed locally for optimal manufacturing efficiency. *Development of a conceptual framework and implementation roadmap for the deployment of standard core processes and technologies locally for optimal manufacturing efficiency.
Issue HR-4, HR-2, and GL-5 (combined): *Executive programs address business management, but not technology workforce continuing education; and *Technical education and training, both internal and external to the enterprise, which currently faces inhibitors, obstacles, and barriers for effectiveness and efficiency, such as government restrictions of mobility of the workforce; and *Discrepancy between academia and industry on future	**Solution GL-5-1, GL-5-2, HR-4-2, and HR-2-3** (combined) *Re-assessment of current approaches to what is taught, how it is taught, with what it is taught, and where it is taught, and development of curricula, pedagogical approaches, and educational resources that reflect the global reality; and *Development of a cohesive, vertically and horizontally integrated education and training programs, optimizing the balance between internal and external delivery. Could be

competence, capability and experience needs	combined with HR; and *Enhanced emphasis is required on continuing education on industry specific technologies as part of job profiles; Professional organizations (ACS, AIChE) who would develop these courses from active collaborative initiatives among industrial thought leaders and academia; and *Develop national and International academic-industry cooperative field programs
Issue HR-1: Graying workforce and technical knowledge: loss of experience and accumulated knowledge and lack of development of next generation.	**Solution HR-1-1:** Broader implementation of knowledge capture processes and practices.
Issue HR-1: Graying workforce and technical knowledge: loss of experience and accumulated knowledge and lack of development of next generation.	**Solution HR-1-2:** Early career development programs designed to accelerate new employee's understanding and capabilities.