NEXT-GENERATION MANUFACTURING PROJECT:
A FRAMEWORK FOR ACADEMIC CURRICULA AND RESEARCH STRATEGY

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Abstract: A short summary of the Next-Generation Manufacturing Project is presented, enumerating and briefly explaining each of the drivers, attributes, dilemmas, imperatives and actions. Possible effects in a technical university are discussed, including new curricula and research topics and partnership aspects concerning education and research. The Modeling and Simulation imperative is detailed for two functional elements of the NGM enterprise: materials processing and resource management. There are also presented some considerations concerning the impact of the e-Learning techniques on the educational methodology.

Key words: NGM Project, Academic Curricula, Academic Research, Academic Strategy.

1. INTRODUCTION

The Next-Generation Manufacturing Project [1] is a broadly accepted framework for next-generation manufacturing enterprises, developed between 1995 and 1997 by individuals from more than 100 American companies, industry associations, government agencies and academic institutions. Manufacturers can use this framework for action as a guide for success in an increasingly complex and competitive global business environment.

The NGM Project identified key competitive drivers of the next-generation environment, defined attributes and imperatives required to respond to these drivers and developed recommendations for actions that industry, government and academia can take to help manufacturers thrive in the intensely competitive and dynamic global markets of the 21st Century.

2. NGM PROJECT SUMMARY

2.1. Drivers

The NGM Drivers are defined as the forces that shape the future competitive environment and exist irrespective of the actions of any one individual, company, or nation. The key drivers of the 21st Century mentioned in the NGM Report are:

- **Ubiquitous availability and distribution of information** – Information systems technology and the knowledge and training requirements of the next-generation workforce are both driven by the universally availability of useful information. The competitive advantage of a manufacturing enterprise will be not the ability to distribute information but the ability to filter and act on the information.

- **Accelerating pace of change in technology** – Some companies are currently predicting skills obsolescence rates of up to 20% per year. Productivity improvements will decrease the size of the manufacturing workforce and smaller workforce demands consideration of how to develop additional “good” jobs both within and outside of manufacturing.

- **Rapidly expanding technology access** – Technology is becoming universally available. Technological and scientific education are spreading worldwide and competitive advantage no longer depends solely on superior technology.

- **Globalization of markets and business competition** – The need of developing countries is not only for jobs and products, but they also demand the latest technology and want to become global suppliers.

- **Global wage and job skills shifts**

- **Environmental responsibility and resource limitations** – Best practices of recycling and conservation, applied to all business functions and all forms of resources, will become an accepted part of the next-generation manufacturing landscape.

- **Increasing customer expectations** – Better solutions result when demands are worked out with suppliers. The trend of joint development of product and process specifications is extending to relationships with customers, with increasing capability to deliver goods and services tailored for small market segments.

2.2. Attributes

Response to the NGM drivers dictates the possession of an integrated set of attributes:

- **Customer Responsiveness** – In anticipation of customers, integrated products and services that fit evolving life-cycle requirements of function, cost, and timeliness will have to be supplied.

- **Physical Plant and Equipment Responsiveness** – An ever-growing knowledge base of manufacturing science will be employed, to implement reconfigurable, scaleable and cost-effective manufacturing processes, equipment and plants that adapt rapidly to specific production needs.

- **Human Resource Responsiveness** – The future workforce will comprise highly capable and motivated knowledge workers who can work in a flexible work environment, with substantial independent decision-making.

- **Global Market Responsiveness** – Manufacturing strategy will be developed to anticipate and respond to a continuously changing global market, with operations and infrastructure tailored to local requirements.
• **Teaming as a Core Competency** – Teaming within and outside the company will be performed, to acquire and focus needed knowledge and capabilities to develop, deliver and support its products and services.

• **Responsive Practices and Cultures** – Core competencies, organizational structure, culture and business practices will continuously evolve, enabling companies to anticipate and respond rapidly to changing customer demands.

2.3. Dilemmas

When trying to define the paths to achieving NGM attributes, many characteristics of the business environment are in apparent conflict. These paradoxes present dilemmas about how to:

• Have employee security without lifetime employment
• Simultaneously satisfy all stakeholder needs
• Practice collaborative knowledge sharing within knowledge-based competition
• Control core competencies without owning them
• Manage assets, when the most valuable asset is knowledge
• Keep domestic jobs while developing global markets
• Reward learning in a reward-for-doing environment
• Maintain national economic and military security with R&D increasingly being done globally
• Deal with transnational corporations.

2.4. Imperatives

Achieving the NGM Attributes and resolving the NGM dilemmas will need a set of enabling practices and technologies.

In the NGM Project, these enablers were clustered into 10 high-leverage Imperatives, as follows, grouped within the four elements of the NGM model:

• **People-Related Imperatives:** Workforce Flexibility and Knowledge Supply Chains – The next-generation workforce will be characterized by innovation, lifelong learning as part of the everyday worklife and new levels of teaming and partnering. Knowledge supply chains are a new concept aimed at radically improving the supply and dissemination of knowledge throughout manufacturing organizations.

• **Business Process-Related Imperatives:** Rapid Product/Process Realization, Innovation Management and Change Management – Instead of separating design from manufacturing, the new concepts are creating a “highly integrated/concurrent environment” in which manufacturing and all other disciplines strongly influence design decisions very early in the product realization process. In this environment, modern innovation and change strategies and practices will also be nurtured and facilitated.

• **Technology-Related Imperatives:** Next-Generation Manufacturing Processes and Equipment, Pervasive Modeling and Simulation and Adaptive, Responsive Information Systems – Information technology will have an ever-greater influence on manufacturing equipment and shop-floor manufacturing processes. Modeling and simulation will reflect a new way of doing business rather than a supporting technology. It will make virtual production a reality. Adaptive, responsive information systems will be reshaped dynamically into new systems by adding new elements, replacing others, and changing how modules are connected.

• **Integration-Related Imperatives:** Extended Enterprise Collaboration and Enterprise Integration – Companies and suppliers (industrial, educational, investment, and governmental) will integrate into a collaborative group. People, processes, systems, and technologies will connect and combine to ensure that, whether operating as an independent unit or and within extended enterprises, the NGM Company can function as a coordinated whole.

2.5. Actions

The widespread implementation of the NGM Imperatives is conditioned by a number of high-level actions that have to be performed:

• Establishment of an NGM Extended Enterprise Demonstration Site to develop and pilot collaborative business and legal processes.
• Development of NGM models and assessment capability to assist companies in planning their evolution to the next generation.
• Development and deployment of a seamless, integrated, interoperable manufacturing environment, providing a common foundation for NGM factories.
• Development of NGM technology roadmaps and apply those roadmaps to guide development of NGM solutions.
• Development of systematic processes for knowledge capture and knowledge-based manufacturing, enabling true enterprise integration and rapid product/process realization.
• Establishment and implementation of methodologies to infuse NGM concepts through all levels of corporations and enterprises.
• Advancing the understanding of innovation and change management to provide a basis for competitive advantage through “step function” improvements of productivity and responsiveness.
• Establishment of a government partnership with industry and academia for a supportive manufacturing infrastructure.
• Enabling and promoting pervasive use of modeling and simulation.
• Development of intelligent processes and flexible manufacturing systems.

3. POSSIBLE EFFECTS ON ACADEMIA

The current chapter is trying to analyze the topics from the NGM Project which seems, at the first sight, to be the most relevant for a technical university and especially for a Manufacturing Engineering Department.

First of all, as mentioned also in the report, the aspects discussed in the NGM Project will have to be continually tested and updated. Universities can play the role of a forum for sharing and evaluating ideas and
research among companies, associations, and government agencies.

Taking into account the valuable studies which already have been published worldwide since the NGM Project Report was released, their conclusions have also to be taken into consideration.

3.1. New fields of study

The concepts of NGM can be part of manufacturing curricula for both engineering and management students, allowing them to have a first contact with the problems faced by manufacturing companies.

Some of the NGM attributes and imperatives can be used to define new topics in technology and business processes, developing new research directions for the academic community and leading to an integrated “Knowledge Supply Chain” as suggested in one imperative.

Later studies [2] had already detailed lists of priority technologies which may be incorporated into academic curricula:
- Reconfigurable Manufacturing Systems
- Waste-Free Processing
- New Materials Processes
- Biotechnology for Manufacturing
- Enterprise Modeling and Simulation
- Information Technology
- Product and Process Design Methods
- Enhanced Machine-Human Interfaces
- Workforce Education and Training
- Software for Intelligent Collaboration Systems

The NGM Processes and Equipment Imperative, for example, is enumerating some research directions:
- Knowledge-based process planning software, allowing alternative manufacturing processes and equipment configurations to be simulated and evaluated before work is released to the floor.
- Shared archives containing reusable process plans and processing configurations.
- Modular machine tools and controls allowing rapid configuration of factories from discrete process equipment and modular control equipment.

In the description of the Adaptive, Responsive Information Systems imperative, the NGM enterprise is supposed to move from a monolithic information system (using a central database in a neutral format) to a ubiquitous service approach in which modules anywhere on the net can be reconfigured in moments to act on data anywhere on the net.

Research for defining a suite of uniform data exchange standards that enable modules to be rapidly interconnected is suggested together with the use of the World Wide Web for this approach.

The Pervasive Modeling & Simulation Imperative is suggesting that research has to be conducted so that all production decisions will be made on the basis of modeling and simulation methods, rather than on build-and-test methods. It is predicted that Modeling and Simulation tools will become available to all those involved in the product realization, production and business processes.

Research has to be performed about modeling the entire enterprise for allowing design, plant, equipment and production processes optimization. Models will include customer requirements and market analysis. Libraries of validated models of equipment and products have to be established in an integrated standardized framework, transforming Modeling and Simulation into a broad-based industry with a range of products, services and brokers.

3.2. Modeling and Simulation

Integrated Manufacturing Technology Roadmapping Initiative was launched in 1998 for leveraging the work done by the NGM Project by defining future manufacturing technology requirements and outlining solution paths to meet these requirements in four interrelated areas:
- Information Systems for Manufacturing Enterprises
- Modeling & Simulation for Manufacturing
- Manufacturing Processes & Equipment
- Technologies for Enterprise Integration

Involving more than 400 individuals representing the manufacturing community, IMTR defined a roadmap for each of the four above mentioned areas, describing the current state of art and practice, providing a vision of the future state and a series of goals, requirements, and tasks to achieve that vision.

The Modeling and Simulation Roadmap [3] is describing these two technologies as emerging keys to support manufacturing in the 21st century, specifying that no other technology offers more potential than M&S for improving products, perfecting processes, reducing design-to-manufacturing cycle time, and reducing product realization costs.

The document defines a high-level plan for Modeling and Simulation technologies to support the IMTR vision of lean, agile, seamlessly integrated manufacturing enterprises. The plan identifies some 40 top-level goals and more than 170 supporting requirements and tasks to achieve the vision, some of the most critical 10 of them including:
- Science-Based Models Integrated with Living Knowledge/Experience Bases
- M&S Is Rule, Not Exception – M&S technology will evolve from a specialized, application- specific tool to a ubiquitous capability
- M&S as Real-Time Enterprise Controller
- Open, Shared Repositories & Validation Centers
- The IMTR M&S Roadmap is organized around the basic function groups inherent to a typical manufacturing enterprise, in the context of modeling and simulation:
  - Product functions
  - Manufacturing process functions
  - Enterprise functions

For each group, after describing the functional elements and the current state assessment, the document is providing a conceptual view of the future state, goals and requirements to achieve that vision (a framework for recommended Research and Development activities).
For example, the Manufacturing process functions group contains eight functional elements from which the fourth, Material Removal/Addition Processes, is described by the following statements:

- Modeling and simulation are readily applied to homogeneous materials; heterogeneous materials greatly increase model complexity.
- The state of technology for interactions at the tool/material interface is based on long-held assumptions, not on scientific understanding of the underlying physics.
- Models and simulations for material removal seldom account for variable machine tool behavior, and assume consistent and predictable performance.
- Rigidity of the machine tool and the part/cutting tool interface is commonly assumed, but is rarely the case.
- Shared knowledge is pervasive; e.g., tooling machining handbook is widely used but is not alone sufficient to practice the state of the art. Expert tools are emerging that select the best machining parameters and cutting tools based on simulations and captured knowledge.
- As is the case with most processes, M&S cannot provide reliable performance predictions for material removal and addition processes involving phase transformations.
- New tools and new materials are not well understood, although M&S tools can have impact. For example, nickel aluminides are desirable in high-temperature applications, but are difficult to machine at room temperature. M&S tools based on metallurgical principles have predicted optimum machining parameters for efficient cutting. As predicted by M&S and verified in practice, dry (coolant-less) machining heats the interface to about 1100 °F and makes machining much easier.

The vision concerning this functional element is described as **Best processes through applied understanding of fundamental principles** and includes an open, shared industrial knowledge base and model library to provide:

- Access to material properties data using standard forms of information representation.
- Means for validating materials property models prior to use in specific product/process applications.
- A fundamental, science-based understanding, including validated mathematical models, of the response of material properties under the stimuli of a wide range of processes.
- Standard, validated time and cost models and supporting estimating tools for the full range of material processing processes.

Two goals are described for the Materials Processing functional element: Broad-Based Material Modeling Framework and Collaborative Analytical Systems, first of them including requirements as:

- Science-Based Material Modeling Knowledge Base
- High-Fidelity, Multi-Model Analytical Applications for Material Forming (Working fluid interface and transfer of momentum and heat to workpieces) and Material Removal/Addition (Tool paths, tooling and fixturing, feeds and speeds, coolants, deposition rates, curing rates, flow, fiber placement, entanglement, and bonding).

The Resource Management functional element (identification, allocation, routing, and control of all operational resources), belonging to the Enterprise functions group, is described by the following statements:

- There are many tools available for modeling different types of resources, for example capacity and manpower planning and estimating, but these are not tied to simulations or the models to each other. An exception to this is that scheduling tools are tied to resource planning for assessment of resources to tasks over time.
- New techniques such as genetic algorithms and neural nets are being used for schedule and control, but they are narrowly focused, user-intensive and not interoperable. Genetic algorithms provide a more efficient way of pruning the search space for potential solutions, but they are very dependent on a good starting point to get good results.
- It is not possible to simulate what is happening at any given time in a manufacturing shop, in order to evaluate problems. Post-event modeling and simulation are expensive, time consuming, and does not have a high probability of success except in clearly defined situations (e.g., single machine failure).
- It is not possible to capture inspection data and superimpose it on a machine's simulation, in order to detect and correct noncompliance to specifications.

The vision concerning Resource Management is described as **Full visibility, accurate prediction, real-time control of distributed operations**, obtained through a model-based control systems that enable real-time, in-depth access to all factory status, performance, and capability information.

The goals for achieving this vision are:

- **Real-Time Factory Model**, requiring **Multiple Constraint Integration and Multi-Resource Optimization**
- **Distributed Resource Management Tools**, requiring **Extended Factory Modeling and Extended Factory Integration & Optimization**
- **Enterprise Knowledge/Skills Management**, including **Model-Driven Training Systems and Embedded Process & Equipment Simulators**.

### 3.3. Knowledge supply chains

Implementing NGM practices, business processes, and technologies will require the combined, collaborative efforts of companies, the community (state and local government, associations, consortia, academia etc.) and individuals. No single entity can bring about the required changes.

The results in the above mentioned fields of study are to be obtained in universities not for themselves but for being passed and applied in NGM enterprises.
The NGM Project is proposing the newly recognized knowledge supply chain in order to apply the concepts of supply chain management to the relationships between industry, universities, schools and associations.

Academia, as a major supplier of knowledge through research and education, must be an integral partner in industry knowledge supply chains and must adapt to the problems raised by this new approach:

- Changing the knowledge supply process from a “push” to a “pull” system, where the defined needs of the customer provide a unified purpose for the total knowledge process.
- Academia must accept the inclusion of the knowledge suppliers in users’ own organizations or enterprises.
- Industry must recognize and capitalize on all the segments of the academic system, especially because it depends on the basic skills taught in the K-12 segment.

The educational roles can be divided between universities and industry:

- The university will generate the basic new knowledge, will develop and substantiate the underlying principles that support the expanding knowledge base of technological and management science and will ensure that this new knowledge is made available and is transferable to a wide set of users.
- Academia translates new knowledge into new teaching and practices so it can be distributed effectively to the total educational system as new talent and new curriculum.
- Industry knowledge-generation will act in the “research” associated with understanding customer needs, adapting best practices and converting new knowledge into new products and services.
- Industry will provide also the main part of the continual education, for the development of its industrial workforce so that knowledge can be efficiently used.

This cooperative integration will foster the following new behaviors:

- Long-term relationships will be the norm. This long-term commitment will move the relationship from one of sponsorship to one of partnership.
- There will be a commitment to spend relevant time in each other’s environment.
- There must be willingness to trust and to capitalize on these partnerships to leverage scarce resources. Willingness to share facilities, equipment, talent, and knowledge will be the key to reducing costs.
- Strategic partnerships with selected companies will assume ownership of certain portions of lifelong learning with those companies.
- There will be established a division of continuous education with a workforce of individuals who would spend a portion of their careers dedicated to distance learning, bringing university knowledge directly to the workplace.
- The formal education system will be expanded beyond the traditional on-campus undergraduate curricula into a more open system in which students spend fewer contiguous years in residence, followed by a period in a mixed internship/working environment.
- Universities will provide education “chits” that graduates could use at any time in the future to renew their education.

3.4. Research partnership

In general, the link between academia and industry is almost exclusively the “graduates”. While industry looks to universities just to provide well-trained students, the university system, in turn, does little follow-up and basically views its commitment to industry as fulfilled once a student has graduated.

This virtual non-use probably results from a combination of historic attitudes and beliefs, derived from the fact that industry and academia do not view each other as partners in the same integrated process.

An attempt to achieve a more productive partnership between industry and academia may start by recognizing the existence of the larger common or unifying purpose. Also, while industry’s problem-oriented research depends on the fundamental knowledge that comes from university, it is often the “pull” of problem-oriented research that stimulates the need for new areas of basic research.

4. THE E-LEARNING INFLUENCE

It is no doubt in the idea that the development of an academic department could not be affected only by the strategies and innovations from the related industry.

The development of the information technology will affect not only the intellectual activities in the universities but also the way in which universities are organized, financed and managed.

The affirmation that the actual status-quo of the academic training system could not and must not be maintained is gathering more and more supporters.

Due to the fact that the technological advance is fundamentally modifying the relation between people and knowledge, some studies are dealing with the idea that the university may disappear as institution, together with the lose of the monopoly on its central function: to create, preserve and transmit the knowledge.

A study performed by the Policy and Global Affairs National Research Council of the U.S.A. National Academies [4] is estimating the following effects of this impact:

- Universities will be transformed in “navigation centers”, while their academic staff will play mostly a facilitator role for identifying and organizing the information [5].
- The barriers between the disciplines will be affected, the way in which the curriculum is designed and the way in which the learning environment is monitored will be transformed. The system of individual courses, each one supported by individual staff will not be able to compete, concerning the cost and quality, with the new educational products.
- The necessity of continuing education will dissolve the borders between students and graduates, leading...
to a network in which, from the first years to the retirement, people will continuously participate to the learning process.

- The technical possibilities for digital reproduction and distribution of the information will affect the foundations of the intellectual property. The need for publishing the research results in recognized printed commercial periodicals will be also affected.
- Academic staff with competencies for development and implementation of a quality e-learning curriculum will have to be partially freed from this activity which is not allowing their professional development and is also not fully recognized. The necessity for training the majority of the staff will appear.
- E-learning will no more be limited to posting on-line courses or to multimedia broadcasts. The most dramatic impact will appear when the whole learning act will be based on new concepts for taking full advantage from the power of information technology.
- The new actors on the educational services market are for the moment focused on adult continuing education and on corporate training. Important investments will allow them to offer high-school and professional school curricula, starting to challenge the traditional education institutions. Migration of the intellectual capital to these new actors will strengthen this effect.

Fortunately, satisfying the need for professional knowledge is not the only reason for the existence of a university.

The educational value of the direct interaction with skilled professors and the social environment from the academic campuses are strongly contributing to the students maturation and to their growth into participative citizenship.

The more important the tests the university will have to pass, the greater its potential to develop its social role. The aspects and the decisions linked to technology development does not have to be seen as threats but as opportunities, the following actions being recommended:

- Development of the university capabilities to follow the technological trends and to adapt its actions, to experiment and to establish alliances with other academic institutions and organizations.
- The technological advance will lead to the convergence of the university with different sectors in which information technology is intensively used, toward a global industry of knowledge and learning. The main objective is not just to manage changes which can be anticipated but to lead these transformations. This will imply common visions between the members of the academic community, between courses, between university and other institutions.
- Like many others social institutions, universities will have to focus on those who are serving, transforming into learner oriented entities, becoming more responsive to what students want to learn (anytime, anywhere and how they wish his) and not on what the faculty wants to teach.

5. CONCLUSION

The set of imperatives and actions recommended for the NGM enterprises has to represent the main source for updating Manufacturing Engineering curricula and research subjects.

The development of Information Systems technology will allow the implementation of Modeling and Simulation techniques in almost all the aspects of a NGM enterprise, shortening the way to the Integrated Enterprise.

Accurate models still have to be developed concerning many functions of the manufacturing enterprise.

Transformation which the industry is expected to suffer will not be fulfilled only by knowledge advance but also through new cooperation strategies between enterprises, university and other partner institutions and organisation.

Life-long learning and product oriented research have to be developed and performed not by separate entities but in networks and knowledge supply chains.

New advances in Information Technology have great chances to significantly modify the whole educational process.

The role of the learners is expected to be modified. There is here a chance for the universities to take the leadership of this change and to manage the way in which this will evolve.

6. REFERENCES


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