From tools to glue

M.J. Wozny

*Rensselaer Polytechnic Institute, Center for Advanced
Technology in Automation, Robotics & Manufacturing
110 8th Street, CII 8015, Troy, New York 12180-3590, USA
Telephone: 518-276-2898 ; Fax: 518-276-4897
E-mail: wozny@cat.rpi.edu*

Abstract

This paper deals with trends in computer-based product realisation, from the early focus on geometry tools to today's focus on information infrastructure: from tools to glue. Setting the stage with a short overview of the evolution of CAD, the discussion then treats NIIP integration protocols, and ends with the recent, big picture, Next Generation Manufacturing framework. The author had some involvement in both of these projects. These two benchmark projects characterise key issues in product realisation.

Keywords

**CAD, CAM, CIM, information infrastructures, standards, product
realisation.**

1 INTRODUCTION

Early CAD (Computer-Aided Design) systems took hold in engineering design, not because they aided design, but because they were a productive tool for modifying engineering drawings. This rapid modification and regeneration of drawings moved the pressure point in the design process from detailed design to analysis. The development of solid geometric modelling in the late 1960's and early 1970's relieved this pressure point by facilitating automatic analyses directly from a computer representation of the geometric model. Solids, and eventually non-manifold geometric models, also allowed the evaluation of manufacturability and other downstream operations to be incorporated into the design process. Today, solid models drive rapid prototyping machines directly, providing a definite, albeit still rudimentary, step toward the fulfilment of «art-to-part»! The ability to extract from the solid model useful information for various downstream operations ultimately led to the concept of a master model, thus setting in place the underlying spine for integration in the product realisation process.

Integration with downstream operations identified a number of nagging problems, such as incorporating in solid modelling the traditional language of manufacturing which engineering drawings represented, namely, a language for building things, rather than just describing geometry. The recent efforts in reconciling the differences between the designer's geometric tolerance specification and the manufacturer's measurement of these tolerances are encouraging.

Another major enabler of integration in design was the need for standardising the exchange of product data, initially as IGES, and now as the much more sophisticated international standard, STEP, and its information modelling methodology, EXPRESS. Such efforts emerged as essential when the manufacturing industry began to off-load everything except core competencies, resulting in complex supplier chain structures.

The National Industrial Information Infrastructure Protocols (NIIP) project addressed the broad product realisation process integration effort, by developing protocols for coalescing into a cohesive whole, the technical standards of product data definition, communication, object technology and workflow management. Its goal is to develop a reference architecture for plugging companies together in a fashion similar to plugging hardware boards into a common bus structure, or plugging application software into a common software protocol backbone.

The rapid changes in recent years dictate it is time to step back and assess where the field is going. The goal of the NGM project is to take a top-down view of manufacturing in light of rapidly changing global environments and create a sound framework for assessing the business environment and developing strategic responses for next-generation success. The most notable result of the NGM study is the importance of the human element in the scheme of things. Once relegated to the obscure background by an automate everything philosophy, the importance of worker synergy with technology is gaining attention.

The seed for this industry-led Next Generation Manufacturing study grew out of a government planning effort in 1994 as part of the President's National Science and Technology Commission.

After outlining the broad NGM methodology, the paper ends with a look at the rapid product realisation imperative.

2 THE NATIONAL INDUSTRIAL INFORMATION INFRASTRUCTURE PROTOCOLS (NIIP) CONSORTIUM

The NIIP Consortium was formed in late 1994 as part of a government contract to establish an open, standards-based software infrastructure protocol (a suite of complementary software standards) for integrating heterogeneous and distributed computing environments across U.S. manufacturing companies. The purpose of the NIIP protocols is to enable formation of temporary consortia of companies (called an industrial virtual enterprise or IVE) for the purpose of exploiting fast-changing business opportunities by sharing costs, information and core competencies. These protocols represent a new form of collaborative computing that supports the transparent sharing of engineering and manufacturing information, allowing IVE's to inter-operate and exchange information in real-time so companies can work as a single integrated unit. The NIIP software reference architecture enables IVE's to synthesise any collection of resources (data, people, hardware, systems, tools, software systems, organisational structures, etc.) and technologies into a viable production system (strategic and operational planning, scheduling and execution, project management, workflow management, and process control in product design and manufacturing). The model of an industrial virtual enterprise is shown in Figure 1.

The NIIP reference architecture takes advantage of existing core technologies in communications, object technology, and product data exchange -- technologies not yet well integrated -- plus an additional technology needed for work and knowledge management of virtual enterprises. Rather than develop yet another system, NIIP works through existing standards organisations to consolidate, harmonise, and integrate the many sets of existing protocols, while at the same time adopting and converging existing standards, and helping to define new ones. The reference architecture defines an integrated infrastructure based on a common communication protocols (Internet), a uniform object technology base for system and application interoperability (OMG), common information model specification and exchange (ISO/STEP), and co-operative work and knowledge management of integrated IVE processes (WFMC, I3, CFI). The terms in parentheses refer to standards organisations, and are defined at the end of this section.

Figure 1: Model of an Industrial Virtual Enterprise.

More specifically, communication services deal with security and information access extensions to Internet for IVE, as well as the integration of Internet tools and environment specific transports under CORBA. IVE services include the interfaces and base classes for IVE agents, negotiators, mediators, and knowledge management. Task management services focus on an integrated user interface and task oriented protocol for inter-operation and co-operation between any collection of compliant data, application, workflow, and communication servers. Lastly, information modelling and interchange services involve user integration and extension of STEP methodologies, tools and interfaces that facilitate virtual enterprise information sharing. Work and knowledge management services provide a framework for managing work activities, such as the arrival of a work order or the completion of a design activity. Decision support is based on the knowledge captured in a work management model.

The standards referred to above include: Object Management Group (OMG) and its Common Object Request Broker Architecture (CORBA), the International Standard for the Exchange of Product data (ISO/STEP), WorkFlow Management Coalition (WFMC), ARPA Intelligent Integration of Information (I³), and the

CAD Framework Initiative (CFI). Details are given in <http://www.niiip.org>. Figure 2 denotes the range of services offered by the NIIIP reference architecture.

Figure 2: Reference Architecture.

The follow-on projects to the basic NIIIP effort described here are various NIIIP application-specific projects. See the NIIIP web site for details.

3 NGM METHODOLOGY

The first step in the NGM methodology is to understand the forces that shape the future competitive environment. They represent self-evident fundamental truths, and exist irrespective of the actions of any one individual, company, or nation. This is the way things are on the verge of the 21st Century. These forces are called the «global drivers.»

The next step is to identify the attributes. Given the lay of the land, what is the vision, e.g., how does one set the compass direction to achieve success in this environment? Stated in another way, what fundamental characteristics or attributes must a company possess that will allow it to take advantage of these global drivers?

The third step is to ascertain the barriers or dilemmas that stand in the way of achieving the vision. These dilemmas represent the issues that must be resolved in order to acquire the attributes.

The next step involves articulating the imperatives, i.e., the key enablers that underlie the resolution of the dilemmas. The final step in the sequence is the creation of an action plan that provides a means for attaining the required enablers. This action plan defines the initial migration path to the next generation.

It is important to realise that the NGM methodology represents a framework for action, and not the details themselves. A company using this framework will need to evaluate the drivers, attributes and imperatives for its own business case, then develop its own metrics for performance measurement as well as its own company-specific action plan.

The NGM project, for the first time, focuses all dimensions of the manufacturing environment to a common, public, comprehensive big picture. It provides an excellent starting point for top-down planning of collective public research opportunities. The report, published in January 1997, is distributed by the Agility Forum. For details, see <http://www.agilityforum.com>.

4 GLOBAL DRIVERS

The seven global drivers developed by consensus are:

- Ubiquitous availability and distribution of information;
- Accelerating pace of change in technology;
- Rapidly expanding access to technology;
- Globalization of markets & business competition;
- Global wage and job skill shifts;
- Environmental responsibility & resource limitations;
- Increasing customer expectations.

Expanding on the first three, which relate to technology issues relevant to this paper, gives a flavour of their implications.

Ubiquitous availability and distribution of information.

With global communications becoming a reality, it is now possible to transmit and receive all types of information everywhere. The primary barrier to instantaneous global information is illiteracy, not the lack of a communication structure. Given that a flood of useful information is universally available, the competitive advantage has shifted from the ability to distribute information to the ability to filter and act on the information, with implications not only for future information systems technology needs, but also for future knowledge and training requirements. Widespread communication also provides the means for virtually every part of the planet to know how the others are living, which in turn will accelerate global human striving for greater standards of living.

Accelerating pace of change in technology.

The continually increasing sophistication of information and communication technology will nourish a sustained growth rate in technology and technological knowledge. A greater understanding of technology, in turn, increases the rate of new development, leading to near exponential growth of ideas, inventions, and products. The expanding array of technology also brings with it an explosion of technical knowledge needed to operate in the next generation. This in turn increases complexity and interdependency in manufacturing enterprises as more and more knowledge is required to fulfil customer expectations. Such rapid changes in engineering and production technology places greater demands on the manufacturing workforce, causing increased rates in skill obsolescence.

Technology change also increases productivity improvements that, in turn, cause the size of the U.S. manufacturing workforce to decrease. Manufacturing labour is also projected to decrease, just as agriculture, through innovation and productivity, increased its output with a smaller and smaller labour force. A smaller workforce, however, does not reduce the importance of manufacturing, but focuses the issue on the creation of additional «good» jobs within and outside manufacturing.

Rapidly expanding access to technology.

As technology becomes universally available, with technological and scientific education spreading world-wide, competitive advantage no longer depends solely on superior technology. Although general access to technology improves the ability to partner and globalize, it also infers a need to constantly upgrade local technological capabilities. There is an ever-present risk that the capabilities of today's latest technology, acquired at considerable expense will be outperformed tomorrow by something less expensive. Large disparities in technical skills between countries are shrinking rapidly, as seen in India, which quickly developed a well-trained technical workforce in software development.

5 ATTRIBUTES

Attributes represent the desired characteristics. The key descriptor in most characteristics essential to manufacturing in the next generation is responsiveness:

- Customer Responsiveness
- Physical Plant and Equipment Responsiveness
- Human Resource Responsiveness
- Global Market Responsiveness
- Teaming as a Core Competency
- Responsive Practices and Cultures

These attributes represent the desired compass heading. They also apply at all levels of manufacturing, in the sense of the fractal factory concept of Warnecke.

Responsiveness requires a different mindset. For example, «Customer Responsiveness» implies the following kind of transitions:

Point Solutions	=>	Total Integrated Solutions
Deliver What is Ordered	=>	Deliver What is Needed
Meet Current Requirements	=>	Anticipate Evolving Requirements
Single Transaction Revenue	=>	Life-of-Customer Revenue
Satisfy Customers	=>	Satisfy Customers & All Other Stakeholders

Focusing on technology related issues, «Physical Plant and Equipment Responsiveness» implies the use of an ever-growing knowledge base of manufacturing science to implement reconfigurable, scaleable, cost-effective manufacturing processes, equipment, & plants that can be rapidly adapted to specific production needs. Thus:

Experience Based Knowledge	=>	Science Based Knowledge
Process Development	=>	Process
Lags Product Needs		
Development Leads Product Needs	=>	Soft Tooling & "Tool-less" Processes
Dependence on Hard Tooling		
Automatic Equipment	=>	Autonomous Equipment
Fixed Capacity	=>	Variable Capacity
Fixed Mission Plant & Equipment	=>	Recyclable Plant, Equipment and Property

Expanding on these issues, the rapidly changing environment of the next generation will require a profound increase in fundamental knowledge of manufacturing processes to supplant today's slow accumulation of understanding and inefficient transfer of experience. This is necessary not only for better quality and productivity, but for developing new innovative processes.

A major impediment to quick response is dependence on complex custom tooling to achieve necessary quality. A transition to fewer tooling-dominated processes and development of more flexible or "soft" tooling can radically enhance flexibility and reduce the time required to take products from concept to development and production.

Machines are now routinely automated, but few are truly autonomous. Product quality and new product start-ups still require considerable supervision and ad hoc adjustment. A transition to machines capable of self-correction, self-diagnosis and on-line quality monitoring will greatly enhance the responsiveness of manufacturing facilities. This intelligent, closed-loop processing capability will dictate a new and deeper understanding of manufacturing processes and the integration of process technology, information management technology, and equipment responsiveness.

Variable capacity is major issue, and is not solved by outsourcing; this simply transfers the problem to the vendor. Instead, it requires innovations in hardware, such as flexible processes, and also innovations in managing plant and equipment.

6 DILEMMAS

The basic issue deals with managing continuous change. Dilemmas arising from the clash of present practices with new global drivers include:

- simultaneously satisfying all stakeholder needs;
- practising collaborative knowledge sharing within knowledge-based competition;
- controlling core competencies without owning them;
- recovering rising plant and equipment costs with shorter product and process lifetimes;
- fostering new markets without creating competitors;
- rewarding learning in a "reward for doing" environment;
- profiting from long-term relationships when customers, suppliers, and partners are becoming less loyal;
- managing knowledge assets, the new discriminator, when the assets belong to the knowledge workers.

7 IMPERATIVES

The ten imperatives or basic enablers deal with creating the new practices, processes and technologies:

People-Related Imperatives

- Workforce Flexibility
- Knowledge Supply Chain

Business-Related Imperatives

- Rapid Product/Process Realisation
- Innovative Management
- Change Management

Technology-Related Imperatives

- Next-Generation Manufacturing Processes and Equipment
- Pervasive Modelling and Simulation
- Adaptive, Responsive Information Systems

Integration-Related Imperatives

- Extended Enterprise Collaboration
- Enterprise Integration

The following paragraphs summarise several of the technology related imperatives.

Knowledge Supply Chain is a new concept aimed at radically improving the supply and dissemination of knowledge throughout manufacturing organisations. It does so by applying concepts of traditional supply chain management to the relationships between industry, universities, schools and associations to rapidly provide and continuously update the knowledge and talent needed to run businesses in a timely and cost-efficient manner.

Rapid Product/Process Realisation is an expected outcome that results from the integration of customer needs and wants, a systematic Integrated Product/Process Development methodology, cross-functional Integrated Product Teams, and a Computer-Integrated Environment. It is accomplished by including, in a highly concurrent manner, all stakeholders in the design, development, and manufacturing process - from concept development through product disposition.

Next-Generation Manufacturing Processes and Equipment are reconfigurable, scaleable, and cost-effective. They are based on a science of manufacturing, in order to adapt to rapidly changing production needs.

Pervasive Modelling and Simulation. Modelling and simulation reflects a new way of doing business rather than a supporting technology. Information technology will make virtual production a reality. Production decisions will be made on modelling and simulation methods, rather than on build-and-test methods. Modelling and simulation tools will move from being the domain of the technologist, to being a tool for all involved in the product realisation, production and business processes.

Adaptive, Responsive Information Systems are information systems that can be reshaped dynamically into new systems by adding new elements, replacing others, and changing how modules are connected to redirect data flows through the total system.

Extended Enterprise Collaboration. An extended enterprise is the seamless integration of a group of companies and suppliers (industrial, educational, investment, and governmental) that collaborates to create and support a timely and cost-effective service or product.

8 RAPID PRODUCT/PROCESS REALIZATION IMPERATIVE

The Rapid Product/Process Realisation (RPPR) imperative integrates all aspects of the voice of the customer and the IPPD methodology to provide an optimised product/process solution that meets or exceeds customer expectations. RPPR is the result of using the following methodologies and tools across the product life cycle:

- integrated Product/Process Development (IPPD) methodology;
- trained, multi-disciplinary Integrated Product Teams (IPT);
- interoperable and integrated Business, Engineering Design and Manufacturing tools;

- integrated Computer Environment (CIE) to facilitate concurrency.

The IPPD methodology provides, uses and develops all the required information to conceive, design, develop, produce, and support effective robust, affordable products and processes. It also provides inherent methods and techniques for their environmentally friendly manufacture and disposal at the end of their expected life cycle. IPPD denotes a more inclusive representation of the development process than do earlier terms of Concurrent Engineering, Simultaneous Engineering or Integrated Product Development.

The Integrated Product Team concept allows continuous and highly concurrent application of all the necessary disciplines, organisational elements, as well as supply chain and various customer entities. They are all simultaneously and interactively involved in the design and development process.

Interoperable and Integrated Business, Engineering Design, and Manufacturing Tools provide the right information, in the right format, to the right people or equipment, at the right time, to make highly fact-based, informed decisions. The tools also provide the means to identify quickly, assess and respond to opportunities resulting from rapidly changing market conditions and customer needs.

The Integrated Computer Environment (ICE) enables the rapid and effective use of product and process information. ICE facilitates rapid creation and flow of information. It allows design and supporting analysis and documentation to be captured automatically as the design proceeds.

The following list illustrates the transitions enabled by RPPR:

<u>Traditional</u>	<u>=></u>	<u>Next Generation Manufacturing</u>
Product or services provider	=>	Life-cycle solutions provider
Sequential product development	=>	Highly concurrent product development
Sales, marketing and engineering control	=>	Incorporating all stakeholders up front in requirements and specifications, generation of requirements, specifications, and solutions
Marketing and/or engineering dictating design	=>	Broad application of synthesis and design process
Minimum customer involvement with	=>	Customer as team member with a long-term typically, and one-time transaction
Islands of domain-	=>	Computer integrated

specific development tools		environment
Working individually (domain experts)	=>	Working in multidisciplinary, cross-functional teams
Self-generated and controlled data	=>	Common, shared enterprise data
Proprietary design systems	=>	Standards-compliant systems
Hard copy drawings, specifications, and	=>	Computer/electronic data requirements data
Bureaucratic review/approval	=>	Rapid decision-making practices and tools
Optimised individual domain-specific	=>	Optimised integrated domains at higher assembly (mechanical, electrical, thermal, levels environmental) CAE, CAD, CAM, CAT for simulating a part
Design for specific performance attributes	=>	Design for all performance and life-cycle attributes
Narrow focus of design, process, equipment, tools	=>	IPT evaluating and approving alternatives and designs involving all affected elements
Design for absolute tolerances	=>	Design for probabilistic subsystem parameters
Singular physical mock-up/prototype	=>	Multiple, iterated electronic prototypes to choose best balanced alternative
After-the-fact Quality Control	=>	Closed-loop predictive process control allowing continuous adjustment
Design confidence via physical testing	=>	Confidence via rules-based design and simulation/virtual testing
Independent flat file information systems	=>	Interoperable, distributed, but linked, business, design, and manufacturing systems

The following enablers need to be researched, integrated, and applied in order to fully realise RPPR:

Systematic Approach using IPPD Methodology:

- Responsive systematic process & information system tools to understand better & proactively predict customer needs & then maintain configuration control of changing customer requirements throughout the product life cycle.
- Early manufacturing participation in decisions to ensure all aspects of the product life cycle are considered in trade-off (productivity, supportability, etc.) starting with system conceptualisation.
- Concurrent development engaging all stakeholders, employing multi-disciplined IPPD teams that include customers, partners & suppliers who participate throughout the product life cycle.
- Digital simulation to minimise dependence on hardware and software prototypes.
- Intelligent closed-loop process control to ensure product quality & minimise need for final product inspection & validation.
- Design emphasis on product line families & process families to ensure reusability, reconfigurability, & scalability.

Integrated Computer Environment:

- Information system tools & methodologies to perform system-level product/process trade-offs between design features & real manufacturing feature costs.
- Standards for unambiguous product/process digital data representation & seamless, public but secure, accessible open systems exchange in a distributed environment.
- New information systems to support new design processes & facilitate electronic commerce within & between the extended supplier chain.

Integration of Development, Approach, Environment, & People:

- Design-to-cost models to enable proper design trade-offs & make-versus-buy decisions.
- Risk analysis to produce a competitive product ensuring process robustness & quality.
- Enhanced design process to reduce risk & uncertainty in product/process technology validation.
- Modular, flexible, & robust design approach & information system tools to ensure the use of fewer but more standardised parts/modules, emphasising re-use of existing designs & processes.

9 SUMMARY

This paper described current trends in product realisation as captured in two representative recent reports that the author was involved. He acknowledges the liberal use of portions of the reports.

Although the NGM study is a high level framework for action, it captures for the first time the totality of the manufacturing. No one-dimensional technology, or management, or business practice slides through the data here! The more than 500 individuals who contributed to this report are commended for their excellent work. On the other hand, the study reveals how complex manufacturing really is. Clearly more work needs to be done in order to create definitive roadmaps, say for research.

The NIIP project represents one of several efforts world wide addressing the technical issues of product realisation. The concept of building on existing standards is a very powerful one, even though some standards efforts progress very slowly. Even more interesting is the emphasis on an underlying theme of collaborative computing, another very powerful emerging concept. Although much narrower in scope than the NGM effort, the NIIP team realised that it had to reduce its scope even farther and attack very specific problem classes.

10 BIOGRAPHY

Dr. Michael J. **Wozny** is Professor of Electrical, Computer and Systems Engineering at Rensselaer Polytechnic Institute in Troy, NY, USA. From 1994 to 1996 he was on leave to the U.S. Government, as Director of the Manufacturing Engineering Laboratory at the National Institute of Standards and Technology, and then as Senior Advisor for Manufacturing Competitiveness to the Under-secretary of Technology, U.S. Department of Commerce. At Rensselaer he established and directed the Rensselaer Design Research Center for 16 years. He has served on various editorial Boards, most recently as Editor-in-Chief of ASME Manufacturing Review. He is chairman of IFIP WG5.2.