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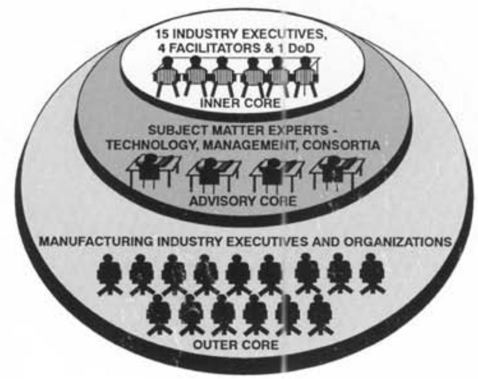

21st Century Manufacturing Enterprise Strategy

Infrastructure

Volume 2

21st Century Manufacturing Enterprise Strategy

Infrastructure

Key Points

- A new competitive environment for industrial products and services is emerging and is forcing a change in manufacturing.
- Competitive advantage in the new system will belong to agile manufacturing enterprises, capable of responding rapidly to demand for high quality, highly customized, products.
- Agility requires integrating flexible technologies of production with the skill base of a knowledgeable work force, and with flexible management structures that stimulate cooperative initiatives within and between firms.
- The Department of Defense has a vital role to play and has a large stake in the success of industry in making the transition to the agile manufacturing.
- The standard of living Americans enjoy today is at risk unless a coordinated effort is made to enable U.S. industry to lead the transition to the new manufacturing system.

Volume 2

This is Volume 2 of a two-volume report addressing the future of American industry. It has been written in response to the transformation of manufacturing practices that is currently in progress. Without the foresight provided by Charles Kimzey, Office of the Secretary of Defense Manufacturing Technology (MANTECH) Office and Steven Linder (Office of the Assistant Secretary of the Navy), this effort could not have been undertaken.

The report is the result of an industry-led consortium partially funded by the Office of the Secretary of Defense Manufacturing Technology (MANTECH) Program and facilitated by the Iacocca Institute at Lehigh University. The contracting office is the U.S. Navy MANTECH Office (Contract #N00014-91-C-0151). The participation of the consortium members was fully funded by their own companies, at a cost estimated to exceed $500,000. This included salaries over a three-month period, when at least half their time was committed to this project, as well as all travel and living expenses. It reflects a major commitment on the part of 13 corporations who contributed executives to the Inner Core, and almost 100 more who participated in two rounds of interaction with the ongoing work of the Inner Core.

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Acknowledgement

For the past six months, a dedicated team has devoted the majority of their energies to bringing this project to a conclusion. The report, in two volumes, represents the completion of the first stage in making America once again a leader in manufacturing. What happens now is in the hands of the great number of industry, government, and academe leaders who must take action to change the thinking, in and about, American manufacturing.

To make this project possible in the short time allotted was a feat that involved many dedicated individuals working as a team. Starting with the concept by Chuck Kimzey, Office of the Secretary of Defense MANTECH Program Office, and the direct guidance of Steve Linder and Leo Plonsky of the Navy MANTECH office, this project took root.

The report, with its hundreds of individual inputs, was organized primarily by Professor Steven Goldman and Professor Kenneth Preiss, for Volume 1 and Volume 2 respectively. Without the immense skill, intellect, and patience of these scholars, the report would not have the insight, nor the support, of the many individuals who made direct contributions.

Next we would like to comment on the stellar effort of the Inner Core team. These men and women worked double-time in fulfilling their "home office" commitments while attending over twenty working sessions in Bethlehem, Pennsylvania. The companies they represented, Air Products, AT&T, Boeing Helicopter, Chrysler, FMC, General Electric, General Motors, IBM, Kingsbury, Motorola, Texas Instruments, TRW, and Westinghouse, made a major contribution of both their executive's time away from their corporate business and the actual dollar cost of the travel and expenses.

Closer to home, the guidance of Lehigh University's President Peter Likins, Provost Alan Pense, Vice President Michael Bolton, and the Iacocca Institute's Executive Director, Laurence Hecht, was invaluable. They provided input and direction for the Inner Core team selection and objective development, as well as constructive comment of the final report.

Finally, as with all major projects, nothing could have been produced without the "behind the scenes" staff. Our research engineers, Orapong Thien-Ngern, Kumar Panicker, and Jorge Leon, teamed to provide endless literature research and technical support. The administrative staff led by Richard Neulight, Bill Jahn, and Joyce Barker oversaw the logistics, draft reports, project tracking and dissemination of information. Finally, the report itself reflected the full meanings of the Inner Core and the authors by the patient typing and formatting by all the project secretaries Robin Lapadula, Lee Hartranft, Veronica Turbedsky and Kathleen Dillon. The style of the finished product was enhanced by editor Len Estrin, illustrator Gene Mater, and designers John Saraceno and Carole Smith.

The total effort of the entire team reflects their attitude toward the project and the goal of providing a vision and the mechanisms to help make America once again a leader in global manufacturing. To all of them, a sincere thank you for the fine effort.

R. N. Nagel & R. Dove
Co-principal Investigators
Iacocca Institute
Lehigh University
Bethlehem, Pennsylvania

Foreword

This is Volume 2 of a two-volume report on the global competitive environment U.S. manufacturing will face, and the infrastructure it will require in order to compete as we transition over the next 15 years into the 21st century. The developments described in the report present a unique opportunity to capitalize on distinctive U.S. strengths; failure to seize this opportunity will put the standard of living of the American people at profound risk.

The report presents the thinking of leading representatives of industry, government and academe. It represents over 7500 man-hours of work and incorporates ideas culled from many excellent recent reports on U.S. industry. The distinctive value of this particular document lies in its presentation of a comprehensive picture of a new system of manufacturing -agile manufacturing- that has begun to emerge in the industrially advanced nations. Our objective in presenting this picture was to assist in defining a strategy and an action agenda that would enable U.S. industry to make the transition to this new system in a timely and competitively effective manner. Volume 1 of the report begins with a description of the opportunity for regaining global competitiveness that the transition to agile manufacturing offers American industry. It continues with a non-technical vision of agile manufacturing as a system in which technologies, management structures, and social values are synthesized into a powerful competitive weapon.

The Opportunity and the Vision chapters of Volume 1 together provide the backdrop for four industrial scenarios. Each is written from the perspective of a successful agile manufacturing enterprise in the year 2006. Together, the scenarios identify the technological, managerial, and social infrastructures that will have to be put in place if such enterprises are to come into being. This volume of the report amplifies the technical details implicit in the creation of these infrastructures.

The ultimate objective of this report is to provoke the actions that need to be taken now in order to restore the United States to world leadership in manufacturing. ***The fact that all of the world's leading manufacturers have to build a new infrastructure to make the transition from mass production to agile manufacturing provides a unique opportunity for U.S. industry to regain the leadership it lost in the 1970s and '80s.*** Only a concerted effort, coordinated by industry, supported by the public, and with the cooperation of governmental and academic institutions can make this happen.

The vision presented here of the infrastructure required for creating agile manufacturing enterprises in the U.S. is, we believe, 80 to 90% correct. The key to making the vision come true, however, is not to make the vision 100% correct, but to immediately take steps to implement it. Refinement of the vision is best accomplished through the experience of working to make it a reality.

If the U.S. is to return to leadership in manufacturing, industry must take the lead in effecting that return. No single corporation, however, not even the manufacturing sector as a whole, can accomplish that task: it is simply too big a job. Only through inter-firm cooperation, and through cooperative, coordinated, efforts among industry, government and academe can that task be accomplished.

The key finding of this report is that there is a common infrastructure requirement for all agile manufacturing enterprises, regardless of their industrial sector. This common infrastructure, described in this volume, will be used in different ways by different industries and different firms within the same industry. Consequently, companies and industries can work together to build the infrastructure, even while competing in the products and services it enables them to provide. The infrastructure will be used to tie production processes together and to integrate those production processes with other parts of the company, and with parts of different companies, into a single system. When the system functions efficiently, it allows companies to easily and quickly meet the needs of a rapidly changing competitive environment. In effect, the infrastructure will enable the formation of agile manufacturing enterprises; capable of responding to the fast-changing market needs and manufacturing demands of a global economy. We believe that competition in the 21st century will be dominated by agile enterprises. ***Those nations that focus now on speeding the transition to agile manufacturing will become the strongest competitors in the global marketplace.***

We have called our report a "21st Century Manufacturing Strategy". Accordingly, the Recommendations section of this volume lays out steps that need to be taken: by industry; by the DoD, which has a vital stake in the success of industry; by Congress and the Executive Branch, which must act to protect the U.S. standard of living; and by academe, which must assume a more active role as an economic development agent.

Because of our concern that this not be just another report, we strongly recommend forming an Agile Manufacturing Forum. The objectives of this forum will be: to facilitate action; to maintain and build on the momentum generated by this project; and to provide a means for ongoing discussion and coordination between all those involved in carrying out the action agendas needed to develop the infrastructure.

After examining the two volumes of this report, we invite you to join us in turning the 21st Century Manufacturing Strategy into reality. The economic well-being and strength of America depends on it.

R N Nagel   Rick Dove

For the Inner Core Team
Roger N. Nagel & Rick Dove
Facilitators

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Introduction

This volume should be read together with Volume 1 of the report, in order to be understood in the correct context. Volume 1 includes the following:

1 The Opportunity

2 Crossing The Threshold: The Vision of the Agile Manufacturing Environment

3 Scenarios From 2006
- UltraComm - Competing Through A Virtual Company Environment
- U.S. Chemicals - Simultaneous Cooperation & Competition
- USASICS - An Open Information Environment
- U.S. Motors - Responds with Agility to Customer Requirements

4 Infrastructure for the Vision
5 Cooperation Mechanisms
6 Summary and Action Agendas
7 Task Description

This Volume 2 describes the infrastructure which will support agile manufacturing in the world of 2006, together with other supporting details for the material of Volume 1.

Reading Volume 2 before reading Volume 1 will give the wrong impression, since Volume 1 sets the context.

This study led both to a vision of what the world of manufacturing will be 15 years from now, and also to an analysis of the infrastructure needed to support that vision. The word infrastructure as used here refers to the *system-wide infrastructure*, not to the technology of individual manufacturing processes. Future developments of individual manufacturing processes are of course important, but were not part of this study. This is explained further in Chapter 2.

This Volume 2, Infrastructure, is aimed at the executive responsible for planning future developments for his manufacturing company, or for the public official responsible for support of developments in manufacturing. The information here is too detailed for a non-technical, high-level executive; and an expert in any one of the infrastructure fields will know more than is expressed here. The aim is to explain and list all the infrastructure to the vision, with enough information so that each subject, and the extent of its current development, is understood, together with detailed recommendations as to what should be done to bring it about, and by whom, industry, DoD, other government agencies, Congress or academe.

Industry is moving into a world of highly fragmented, changing and unpredictable markets and economic factors. Industry in order to survive will deal with constant change as a way of life. This drives many changes in the company. The major move under way now is to reorganize workers into teams where individuals in the teams are empowered to make decisions in order to get a job done quickly. The tools those employees have will include very powerful computer communication systems to enable such a team to interact between its members when it is distributed over a large geographical region, or to enable distributed teams to interact. The functioning of individuals in manufacturing companies will be moving from the world of individual specialists to a world of "renaissance teams". Manufacturing will respond to challenges by emphasizing the qualities of

- ***agility***
- ***quality***

Pervasiveness changes system characteristics

Compare ——————————>	*With*
doing business in a world where ***fax*** machines were the ***exception*** some years ago	doing business in a world where ***fax*** machines are the ***rule*** as it is now
doing business in the ***stock exchange*** when use of ***computers*** and communications was the ***exception*** 15 years ago	doing business in the ***stock exchange*** when use of ***computers*** and communications is the ***rule*** as at is now
the military impact of today's capability where ***rapidly developed*** and produced devices are the ***exception***	the military impact of industrial capability in 2006 when ***rapidly developed*** and produced devices will be the ***rule***

The technologies and techniques employed to achieve that are known today; as their use becomes pervasive, they change the whole system.

Every one of the characteristics that can be foreseen for manufacturing in the year 2006 exist today in various companies. The difference is that what is the ***exception today*** will become the ***rule tomorrow***. What is ***unusual today*** will become ***pervasive tomorrow***. That does not sound like a major change, but in fact it is. The pervasiveness of the application of those technologies generates qualitative changes in our way of life and our way of doing business. Similarly, the pervasive use of computer technology, when tied together with the empowerment of individual employees will lead to a fundamental change in the way industry is managed.

Elsewhere in this report can be found descriptions of how rapid work generated technical solutions in a very short time, useful in the Gulf War, such as the anti-fratricide identification device. From a systematic point of view those projects, although dramatic, could never have taken place on a large scale. The reason is that those technical solutions were not integrated into logistics and the regular planning procedures in the military. The military could deal with a few exceptional developments which made a major difference but many developments made quickly could not have been integrated into the organization of industry and military logistics. Many simultaneous rapid developments would likely have led to more chaos than order. However, 15 years from now rapid product realization and rapid product introduction and rapid reconfiguration and upgrade of products, which will be widely adopted in industry, will create a situation where rapid developments can in fact be integrated into industrial and military systems. We have today the ability to quickly create technical solutions and to dispatch them to the customer. We are not yet capable of using that capability very well. Fifteen years from now that capability will be pervasive and people in all kinds or organizations through industry, retailing and the military will understand and will know how to make best use of rapid product realization and product introduction, and will integrate such rapidity into work systems.

The capability to rapidly realize a product and to deliver a specially-configured product rapidly to a customer, will be by 2006 much more widespread than in the 1990s. That does not imply that every product will be produced and delivered rapidly. The capability will be in place to use that rapid response, and management then will have the freedom to decide on the timing of processes, on inventory levels, and on marketing decisions, with manufacturing capable of managing any timetable. The quick reaction capability enables management to decide dynamically on manufacturing rates based on whatever considerations they like so levels can fluctuate as desired. Marketing can decide on a price and delivery time for various products. There can then be quick-reaction and slow-reaction variations of the same products, for different markets and prices. Not every product will be produced at top speed, but different products will be made at different speeds, as the market requires. The manufacturing system will be able to respond as agilely as needed.

The capability to rapidly realize a product and to deliver a specially-configured product rapidly to a customer, will be by 2006 much more widespread than in the 1990s. The manufacturing system will be able to respond as agilely as needed.

Agility will be in place, to be used as needed, and to allow management the freedom to "drive" products faster or slower as the market wants. By being introduced incrementally, with modular components, as part of industry's move to network-based manufacturing, agility will not incur special cost. There is no need to be concerned now in 1991 with how much manufacturing will be quick response agile work and how much will be slower. That is irrelevant. What is important is to put the quick response system in place, to free the moneymaking levels of management from the shackles of slow, old paradigm mass production concepts.

All manufacturing will change, not only quick-response manufacturing. Manufacturing dealing with large runs of commodity items will also be radically changed. By 2006 quality will be an implicit requirement of all manufacturing in the affluent societies. By 2006 industry will deal well with energy, pollution and waste, because of individual attitudes and societal pressure as well as government regulation. These requirements also will change industry considerably.

These changes will change concepts. For instance, today one can reasonably say "I want a weapons system (helicopter, airplane, tank, missile, etc.) cheaper and quicker". That is a sentence caught in the old mind-set. Why? Because we are used to thinking of a weapons system as basically constant, with some life span, with a certain number of preplanned product improvements for midlife retrofit or update. The new mindset will see a weapons system as always subject to constant change. The tank, airplane, helicopter, missile, jeep or whatever will be designed to accommodate, as much as feasible, change. At any point in time, a given percent of inventory will be back in the factory being updated with new and improved electronics, or engines, or transmissions, or driver or pilot spaces, or whatever. Under these circumstances, design of the technical manufacturing system will be as important as the design of the weapon itself. The manufacturing system will need to exist to continuously reconfigure the product and will be needed to keep the product alive. Industry and DoD procedures, individual skills, and organization will be built to deal with continuous change.

The manufacturing system will be able to deal with change as agilely as wanted. Change of a weapons system will not be a major decision, seldom taken. Defense decisions will not be whether to change a system, but how fast to do it. Based on analysis of threats and available budget, a commander will be able to decide, any year "20% of this system will get reconfiguration a, 10% will get reconfiguration b, and 50% of that system will also get reconfiguration a."

The manufacturing system will respond as fast as needed; speed of response of manufacturing will not constrain military decisions. This speed would involve no specially high investment of money, if it is developed and installed incrementally as a part of the regular annual national investment in the infrastructure for industry, rather than as a sudden renewal of large enterprises.

The new paradigm thinking will change many perceptions including the perception of a production machine. In tomorrow's world every manufacturing process will receive and send large quantities of data, and the systems-wide and local impact of this information should be as much a part of process development as is the physics and chemistry of the process. This embedding of a process machine into a system is similar to past developments in another system, that of the military. Whereas forty years ago the design of a manned weapon such as a tank or airplane concentrated almost all the weapon itself, with the connection to command and control being secondary in the design process, today the connection to command and control is a significant upfront design consideration. The connection of process machines to the total manufacturing system will follow a similar path.

OVERVIEW

The picture of agile manufacturing described in these scenarios emerged over many hours of discussion with the inner core team. The team met two days a week, for six weeks, studying reports and listening to presentations on future directions for manufacturing. Ideas from advisory core experts were investigated, detailed and talked through to consensus. Subsequently, the inner core divided into groups in order to identify agile manufacturing enterprise characteristics, system elements and enabling subsystems for each of the scenarios in this report: the automobile industry sector, the semi-conductor sector, the continuous process sector, and a multi-corporation communication product. Members rotated between groups from time to time for cross-fertilization of ideas and to share responses from colleagues back in the member's "home" corporation.

During this long, intensive, series of meetings, each of the four scenarios was analyzed, dissected and debated in depth. At the start of that detailed and intensive work, it was not at all clear that the scenarios would have similar characteristics, nor was it clear what the manufacturing systems elements would be for each of them. As the work progressed, convergence to a common set of characteristics, systems elements and enabling subsystems manifested itself. From the many proposed items, a core set emerged as central to all the scenario sectors analyzed. This core set extends over all manufacturing and is presented in Figures 1 to 3. These figures show the same data, from different points of view. Figure 1 shows in one page the competitive foundation, the enterprise characteristics which will be required, the elements of the manufacturing enterprise and the implied enabling subsystems which will enable these manufacturing enterprise elements. The advantage of this presentation is its conciseness, in one page; the disadvantage is that categorization is not shown. Figure 2 shows the data of Figure 1, but with the major subsystems of each element shown. This Figure shows the categorization but can give rise to a misunderstanding. All subsystems will affect each enterprise element. Figure 2 shows the major subsystems for each element, without implying that the other subsystems have no effect. Figure 3 shows a matrix of enterprise elements against enabling subsystems, divided into technical and non-technical subsystems. The relationship is indicated as being a critical enabling subsystem for an enterprise characteristic, an important subsystem, or a minor subsystem.

This material was presented during the course of the project to the outer core, over 100 senior industrial professionals who deal with manufacturing, in groups of about 20 at a time. Their responses broadened the consensus that there is indeed a common pattern of agile manufacturing systems characteristics. There is also a wide consensus that the material presented in this report is representative of the core of the infrastructure for the new manufacturing system.

Agile manufacturing will require a new and novel infrastructure. As discussed here, the infrastructure does not include individual processes such as semiconductor fabrication details, metal removal processes and the like, important as they are. The infrastructure discussed here is that needed to support the nation-wide and corporation-wide levels of agile manufacturing systems. It can be compared to the national network of roads and highways that enables the use of automobiles and trucks. Today, many groups are occupied with designing new high performance production technologies, the cars and trucks of the manufacturing system, but little attention is being paid to the system infrastructure. The accompanying diagram presents the essence of that infrastructure. It shows, for the competitive foundation of agility and quality, 18 characteristics needed for the agile manufacturing enterprise as a whole.

Figure 1 is the essence of the infrastructure which will support that new development. It shows, for the competitive foundation of agility and quality, the 18 characteristics needed for the enterprise as a whole. These characteristics are described in the section immediately following Figure 1. Those enterprise characteristics are supported by the nine manufacturing enterprise elements of business metrics and procedures, communication and information elements, cooperation and teaming factors, enterprise flexibility elements, enterprise-wide concurrency elements, environmental maintenance elements, human elements, subcontractor and supplier support elements, and technology deployment elements.

The manufacturing enterprise elements are described later in the next section.

The elements of the manufacturing enterprise which support the enterprise characteristics are made possible by the enabling subsystems shown in Figure 1. These are described in the section which follows the enterprise elements.

Success in the new manufacturing era will be achieved only by dealing with the enterprise as a whole. It cannot be achieved by dealing only with manufacturing as narrowly viewed today.

Manufacturing will permit rapid response to product opportunities; the leading companies will proactively seek out those products and markets for which their agility in providing quality products gains for them an advantage. This will be achieved only by empowering individuals, creating teams, breaking down hierarchy, installing the required production machine and software and changing the whole cooperation so that it is capable of such agility. In short, the industrial corporation as a whole must change in order to achieve agility. Those companies that succeed in making the change will win; those that don't, will wither.

COMPETITIVE LEADER 2006 - THE AGILE ENTERPRISE

COMPETITIVE FOUNDATION & CHARACTERISTICS

COMPETITIVE FOUNDATION

- Continuous Change
- Rapid Response
- Evolving Quality Journey
- Environmental Responsibility

ENTERPRISE CHARACTERISTICS

- Concurrency
- Continuous Education
- Customer Responsive
- Dynamic Multi-Venturing
- Employees Valued
- Empowered Individuals in Teams
- Environmentally Benign
- Flexible (Re-) Configuration
- Information Accessible & Used
- Knowledgeable Employees
- Open Architecture
- Optimum First-Time Design
- Quality Over Product Life
- Short Cycle Time
- Technology Leadership
- Technology Sensitive
- Total Enterprise Integration
- Vision-Based Management

MANUFACTURING ENTERPRISE ELEMENTS

- Business Environment
- Communication & Information
- Cooperation & Teaming Factors
- Enterprise Flexibility
- Enterprise-Wide Concurrency
- Environmental Enhancement
- Human Elements
- Subcontractor & Supplier Support
- Technology Deployment

IMPLIED ENABLING SUB-SYSTEMS

- Continuous Education
- Customer Interactive Systems
- Distributed Databases
- Empowered Individuals & Teams
- Energy Conservation
- Enterprise Integration
- Evolving Standards
- Factory America Net
- Global Broadband Network
- Global Multi-Venturing
- Groupware
- Human-Technology Interface
- Integration Methodology
- Intelligent Control
- Intelligent Sensors
- Knowledge-Based Systems
- Modular Reconfigurable Process Hardware
- Organizational Practices
- Performance Metrics & Benchmarks
- Pre-Qualified Partnering
- Rapid Cooperation Mechanisms
- Representation Methods
- Simulation & Modeling
- Software Prototyping & Productivity
- Streamlined Legal Role
- Supportive Accounting Metrics
- Technology Adaption & Transfer
- Waste Management & Elimination
- Zero-Accident Methodology

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COMPETITIVE LEADER 2006 - THE AGILE ENTERPRISE

COMPETITIVE FOUNDATION & CHARACTERISTICS	MANUFACTURING ENTERPRISE ELEMENTS	IMPLIED ENABLING SUB-SYSTEMS
COMPETITIVE FOUNDATION ■ Continuous Change ■ Rapid Response ■ Evolving Quality Journey ■ Environmental Responsibility **ENTERPRISE CHARACTERISTICS** ■ Concurrency ■ Continuous Education ■ Customer Responsive ■ Dynamic Multi-Venturing ■ Employees Valued ■ Empowered Individuals in Teams ■ Environmentally Benign ■ Flexible (Re-) Configuration ■ Information Accessible & Used ■ Knowledgeable Employees ■ Open Architecture ■ Optimum First-Time Design ■ Quality Over Product Life ■ Short Cycle Time ■ Technology Leadership ■ Technology Sensitive ■ Total Enterprise Integration ■ Vision-Based Management	Business Environment Communication & Information Cooperation & Teaming Factors Enterprise Flexibility Enterprise-Wide Concurrency Environmental Enhancement Human Elements Subcontractor & Supplier Support Technology Deployment	■ Continuous Education ■ Customer Interactive Systems ■ Distributed Databases ■ Empowered Individuals & Teams ■ Energy Conservation ■ Enterprise Integration ■ Evolving Standards ■ Factory America Net ■ Global Broadband Network ■ Global Multi-Venturing ■ Groupware ■ Human-Technology Interface ■ Integration Methodology ■ Intelligent Control ■ Intelligent Sensors ■ Knowledge-Based Systems ■ Modular Reconfigurable Process Hardware ■ Organizational Practices ■ Performance Metrics & Benchmarks ■ Pre-Qualified Partnering ■ Rapid Cooperation Mechanisms ■ Representation Methods ■ Simulation & Modeling ■ Software Prototyping & Productivity ■ Streamlined Legal Role ■ Supportive Accounting Metrics ■ Technology Adaption & Transfer ■ Waste Management & Elimination ■ Zero-Accident Methodology

CRITICAL ENABLING IMPLIED SUBSYSTEMS FOR EACH MANUFACTURING ENTERPRISE ELEMENT

(Subsystems which support each element, but are not critical for the element, are not listed here)

- **Business Environment Elements**
  - Enterprise Integration Subsystems
  - Global Multi-Venturing Subsystems
  - Organizational Practices
  - Performance Metrics and Benchmarks Subsystems
  - Pre-Qualified Partner Subsystems
  - Rapid Cooperation Incentive Subsystems
  - Supportive Accounting Metrics Subsystems
  - Streamlined Legal Subsystems
- **Communication & Information Elements**
  - Distributed Database Subsystems
  - Enterprise Integration Subsystems
  - Evolving Standards Subsystems
  - Factory America Net Subsystems
  - Global Broadband Public Network Subsystems
- **Cooperation Elements**
  - Empowered Individual and Team Subsystems
  - Enterprise Integration Subsystems
  - Factory America Net Subsystems
  - Global Multi-Venturing Subsystems
  - Groupware Subsystems
  - Rapid Cooperation Mechanisms
- **Enterprise Flexibility Elements**
  - Human-Technology Interface Subsystems
  - Integration Methodology Subsystems
  - Intelligent Control Subsystems
  - Intelligent Sensor Subsystems
  - Modular Reconfigurable Process Hardware
  - Software Prototyping & Productivity Subsystems
- **Enterprise-Wide Concurrency Elements**
  - All Cooperation Element Subsystems
  - All Technology Deployment Element Subsystems
  - Enterprise Integration Subsystems
  - Factory America Net Subsystems
  - Representation Subsystems
  - Simulation and Modeling Subsystems
- **Environmental Maintenance Elements**
  - Energy Conservation Subsystems
  - Waste Management and Elimination Subsystems
  - Zero-Accident Methodology Subsystems
- **Human Elements**
  - Continuous Education and Training Subsystems
  - Customer Interactive Subsystems
  - Empowered Individual and Team Subsystems
- **Subcontractor & Supplier Support Elements**
  - All Cooperation Element Subsystems
  - All Technology Deployment Element Subsystems
  - Evolving Standards Subsystems
- **Technology Deployment Elements**
  - Continuous Education and Training Subsystems
  - Human-Technology Interface Subsystems
  - Knowledge-Based Software Subsystems
  - Technology Adaption and Transfer Subsystems

Figure 2

NON-TECHNICAL ENABLING SUBSYSTEMS

MANUFACTURING ENTERPRISE ELEMENT

	Business Environment	Communication & Information	Cooperation and Teaming Factors	Enterprise Flexibility	Enterprise-Wide Concurrency	Environmental Maintenance	Human Elements	Subcontractor & Supplier Support	Technology Deployment
Continuous Education	○	○	○	○	●	○	●	●	●
Empowered Individuals & Teams	○	○	●	○	●	○	●	●	○
Organizational Practices	●	○	○	○	○	○	○	○	○
Performance Metrics & Benchmarks	●	○	○	○	○	○	○	○	○
Pre-Qualified Partnering	●	○	○	○	○	•	○	○	○
Rapid Cooperation Mechanisms	●	○	●	○	●	•	○	●	○
Streamlined Legal Systems	●	○	○	○	•	○	○	○	○
Supportive Accounting Metrics	●	○	○	○	●	○	○	○	○
Technology Adaption & Transfer	○	○	○	○	●	○	○	●	●

● means that the enabling subsystem is a critical component of the manufacturing enterprise element.

○ means that the enabling subsystem is a helpful component of the manufacturing enterprise element.

• means that the enabling subsystem has only a weak influence on the manufacturing enterprise element.

Figure 3b

TECHNICAL ENABLING SUBSYSTEMS

MANUFACTURING ENTERPRISE ELEMENT

	Business Environment	Communication & Information	Cooperation and Teaming Factors	Enterprise Flexibility	Enterprise-Wide Concurrency	Environmental Maintenance	Human Elements	Subcontractor & Supplier Support	Technology Deployment
Customer Interactive Systems	•	○	○	○	○	•	●	•	•
Distributed Databases	○	●	○	○	○	•	○	○	•
Energy Conservation	○	•	•	•	•	●	•	•	○
Enterprise Integration	●	●	●	○	●	•	○	●	○
Evolving Standards	○	●	○	○	○	○	•	●	○
Factory America Net	○	●	●	○	●	○	○	●	○
Global Broadband Network	○	●	●	○	○	○	○	○	○
Global Multi-Venturing	●	○	●	○	●	•	○	●	○
Groupware	○	○	●	○	●	•	○	●	•
Human Technology Interface	•	○	○	●	●	•	○	●	●
Integration Methodology	•	○	○	●	○	•	•	○	○
Intelligent Control	•	○	•	●	○	○	•	•	•
Intelligent Sensors	•	○	•	●	○	○	•	•	•
Knowledge-Based Systems	○	○	•	○	●	○	○	●	●
Modular Reconfigurable Process Hardware	•	•	○	●	○	•	•	•	○
Representation Methods	○	○	•	○	●	•	•	○	○
Simulation & Modeling	○	○	•	○	●	•	•	○	○
Software Prototyping & Productivity	•	○	•	●	○	•	•	○	•
Waste Management & Elimination	○	•	•	•	•	●	•	•	•
Zero-Accident Methodology	○	•	•	•	•	●	•	•	•

Figure 3a

Enterprise Characteristics

The following section describes in greater detail the elements shown on the chart below. Why these were considered important and what the critical components are for each is also included in the following pages.

- Concurrency
- Continuous Education
- Customer Responsive Pull Organization
- Dynamic Multi-Venturing
- Employees Valued
- Empowered Individuals in Teams
- Environmentally Benign
- Flexible (Re-) Configuration
- Information Accessible & Used
- Knowledgeable Employees
- Open Architecture
- Optimum First-Time Product Design
- Quality Over Product Life
- Short Cycle Time
- Technology Leadership
- Technology Sensitive
- Total Enterprise Integration
- Vision-Based Management

Concurrency

The agile company, responding quickly to the opportunity to succeed with a quality product, will require that all the parts of the enterprise work simultaneously to seize an opportunity. This includes all the functions, not only engineering and manufacturing, but marketing, finance, human resource management and all other departments.

This implies that some groups will be needing to make progress before getting complete data from other groups, and will learn to succeed notwithstanding insufficient information as they work. This also implies that people and teams all across a single corporation, and across multi-corporation projects, will need to be in constant communication, updating others on their work, and being updated.

This will require individual skills and adaptability, supportive management methods, and a technological communication infrastructure, of scope and intensity far beyond anything known today. Tools will be needed to evaluate options, send and receive data, analyze technical solutions and marketing opportunities, and to rapidly move to production. The small oases of such capability today will become a vast network of concurrent capability.

Continuous Education

The employees and their skills will be perceived as the major asset of a corporation (see "Employees Valued" later). This asset will be constantly improved and skills added to it, for the good of the company. This will require constant enterprise-wide evaluation of the skills in the corporation, and the standard of those skills. Human resource management will plan the annual training and education for each employee. It is foreseen that on the average, employees will spend several weeks a year in total in training and education.

This will include not only training to use a particular system or machine, but training for improvement of all a person's skills. People will rotate in and out of teams, and will be capable of succeeding in several functions. In the successful corporation there will be many global ventures and cooperative projects, and so understanding the culture, history and language of foreign countries will be important.

In order to be efficient, continuous education planning will be an important senior function. Technological tools and novel educational methods will expand to fulfill this need with the least cost.

Customer Responsive Pull Organization

The whole enterprise, not only the technical functions, will support quick response team reactions to customer demands. Teams in the organization will proactively search out customers with special demands, and will promise them quick delivery. Every person, team and function in the organization will respond to support each opportunity quickly and correctly.

The whole company, and manufacturing a part of that, will orchestrate its activities according to customer input. The annual plan for a company will not be a list of production targets based on sales forecasts, but a plan of processes to develop and produce products rapidly as the opportunity arises.

This competitive demand will generate new skill requirements from employees, new organization and relationships between functions, new teaming arrangements, and a much augmented infrastructure of communications, computer simulation, evaluation and decision support processes, and manufacturing machines, to achieve this.

Dynamic Multi-Venturing

Business opportunities will be created at an ever-increasing rate. No corporation, however large, will have within it all the skills and capabilities to quickly put a team together to take advantage of each opportunity. They therefore will move into joint ventures. Compared to joint venturing as it is today, in the competitive company, there will be many, more often. Joint venturing will be common. Lower-level managers will be authorized to commit to them. Standard procedures quickly implemented will be available to put them in place. The venturing will include people from all functions of an enterprise.

A kaleidoscope of many ventures will be seen in a corporation as ventures are formed and ended, pervasively and intensely. This will require empowerment of lower-level individuals in teams, a legal, accounting and administration procedure to facilitate this, and evaluation and motivation of individuals to promote multi-venturing. Also, the technical systems in a company will have to be "plug compatible" so that as ventures are started, the teams in each company can get to work on their common goal quickly and seamlessly.

Employees Valued

For a manufacturing organization to compete in the world of ever-increasing change, speedier product cycles, and customer pull, each employee will have to see himself as proactively part of the total enterprise effort, using his/her skills and motivations to bring victory to his/her team and success to the corporation. Employees are then not perceived as an expense to be trimmed as much as possible, firing when one can and hiring only when one can't avoid it. The knowledge and motivation of the employee will be a major company asset, constantly evaluated, nurtured and improved.

This new and different approach will lead to a complete refocus and reconstruction of the successful corporation, with the systems and infrastructure in place to deal well with the valued asset -- the employee.

Empowered Individuals in Teams

The knowledge and capability required to find and take advantage of opportunities in the rapidly changing business environment of the future will require that people work in mission-oriented teams. The team will be able to independently make many decisions without prior approval, so as to complete its mission well and quickly. This is empowerment of the people in the team to make the decisions as they see fit.

For this to succeed needs reorientation of management approaches, reducing hierarchies, new employee evaluation systems, and management which tolerates risk and error, and also requires a technical infrastructure which enables a team to communicate with other teams and company functions so as to correctly evaluate alternatives, to inform and be informed. The enterprise integration systems, factory America net, and other subsystems enable such rapid and reliable communication and computing.

Environmentally Benign

The last quarter of the twentieth century witnessed the genesis of environmental sensitivity with respect to manufacturing processes. Government regulations, recycling consciousness, wastewater treatment, political action environmental groups and other factors led to the insistence that manufacturers take ever more care with regard to environmental issues. For the next generation environmental sensitivity will become an implicit part of our society and culture, integrated into the manufacturing process. Both the product and the production process that enabled it will be environmentally benign - or will be disallowed. Neither the Government nor the individuals who collectively create society will tolerate environmentally insensitive products or production processes.

Flexible Reconfiguration

The competitive enterprise of 2006 will be able to create opportunity for rapidly seizing business initiatives, for rapidly realizing and producing a product, and will enable the customer to make a decision then respond to that rapidly. That will require the company to rapidly put together mission-oriented task forces, and to rapidly reconfigure as needed, marketing, manufacturing and administrative functions in the enterprise.

This is similar to the practice in the military of putting together a task force or battle group with a mix of units, their skills and equipment, tailored to a specific mission. When the military is faced with a task for which the regular organic structure seems unsuitable, they can within a very short time reconfigure a specially tailored force, with suitable command and control and weapon systems, for the mission at hand. Industry will deal in an analogous way, flexibly reconfiguring a group of people and processes to deal with a mission.

The people in the successful enterprise will have the skills and motivation to adapt, as needed. The technical subsystems of communication, information, engineering, manufacturing will be built from modules such that they can be easily and rapidly reconfigured so as to seize business opportunities.

Information Accessible and Used

The competitive company will gain its success from the skills of its employees. Mission-oriented, empowered teams will be working with customers to produce products and profits agily and with quality. These teams to succeed will need rapid access to much information of all kinds in the enterprise.

The highly intense joint venturing will succeed only if the members of an inter-corporation team have rapid access to information, and that means giving employees of other corporations access to information. That happens today. There are companies linked together in various kinds of ventures and stakeholder relationships in which information is very open -- even as companies cooperate and compete simultaneously. For the successful corporation of 2006, there will be so much more teaming and multi-venturing than today, that much, much more information will be available and used than today. The financial benefit of teaming and multi-venturing will outweigh the benefit of secrecy and limited information flow.

This will require great extension of networks, information and enterprise integration subsystems, of standardization, and of skill training by workers.

Knowledgeable Adaptable Employees

The competitive enterprise of 2006 will rely upon the knowledge and adaptability of its workers, in mission-oriented teams and all through the company, to create business opportunities and to react speedily to challenges.

The product and the production processes are not just machines. They include implicitly the experience and know-how of the people designing and dealing with them. The company that best harnesses that knowledge into its products and processes and whose workers are more knowledgeable and adaptable, will establish a strategic advantage.

To succeed in that, a company will put in place subsystems for education and skill and motivation improvement of the employees, together with management and technical systems which will allow the knowledge and adaptability of the employees to be used to maximal advantage.

Open Architectures

The competitive enterprise of 2006 will be constantly forming teams and joint ventures. For these to function efficiently, quickly and effectively, the work systems and, most importantly, the communication and information systems, will be able to rapidly connect together and be functional.

This requires that the systems will be built on open architectures, so that companies can prepare themselves for quick teaming and joint venturing.

This in turn implies that all the subsystems of networking, information, and communication, be built around open architectural principles. The corporation which does not subscribe to this will, in effect, cut itself off from the prospect of dynamic venturing and agile, multi-divisional and multi-corporational teaming.

Optimum First-Time Product Design

Given the rapidity of response required by the successful 2006 corporation, products will be designed much more speedily than in the past and in many organizations the products will be designed optimally the first time. The product of the future must arrive in the marketplace quality matured, reliable, and on time.

In current methods, a product is developed by a process of design, analysis, prototype, test, improve the design, and so on in a cycle. By 2006, design analysis and simulation tools will have improved considerably, as will production process simulation and analysis tools. Those tools will enable a team to design a product whose first prototype will test successfully and be produced, with a much higher rate of success than today.

Quality Over Product Life

The meaning of the word "quality" is changing to go beyond "zero defect". As the goal of effectively no defects in a product is reached by more and more companies, the leaders are redefining the word to mean zero defects together with customer gratification. Products are being engineered not only for no defects, but for customer delight with every detail. That concept is being extended even further, and by 2006 the successful corporation will have established customer satisfaction with the product over the life of the product.

For example, as sensors develop, we can expect many products to include diagnostic systems which may communicate directly with the service center. There will be cars with such systems, and the owner will be called to notify when and how maintenance will be done. There will be household machines with such systems, and repair and maintenance will be done as needed, part of the service, without the owner needing to order it.

Quality, in the meaning of zero defects, will be implicit and will not be even mentioned.

Embedding of the new quality in a product requires developments in the supporting subsystems of sensors, control, information regarding the product and the production process, in analysis and simulation, as well as other subsystems.

Short Cycle Time

How fast does a 100 yards champion need to run? A fraction faster than the competition. How fast does product cycle time need to be? A fraction faster than the competition.

The enterprise as a whole will constantly be examining its own structure, and the structure and performance of all of its units, to find ways to cut time from all its processes. Not only from technical manufacturing processes, but from all the administrative and other processes in the enterprise. Cutting down product realization time, product production time, and total customer response time, while improving product quality, will place a never-ending pressure on a company to improve.

To achieve this will require motivated and skillful people, structured in teams who can respond quickly, incisefully and successfully. They will be equipped with the best technology and will be constantly striving to get even more out of the technical systems, in order to be fast to market, and to be the quickest supplier.

Technology Leadership

The competitive manufacturing company of 2006 will have the people and the technology to agily produce quality products. To be able to compete successfully, and to be a senior partner in a multi-venture, the company will exhibit leadership in some technologies. A technology leader will be a sought-after partner, not just another company.

The leadership is not only in the manufacturing processes of the company, but even more, in the skills of its employees.

Creating and maintaining technology leadership will require imaginative vision-based management, and empowerment of individuals. Technology leadership derives not from edict in a hierarchic management structure, but from motivation and skill of employees, and a supportive management. It also requires giving the employees in the technology leadership role the best in information systems, education and equipment, so as to constantly be in the technology leadership role.

Technology Sensitive

The successful competitor of 2006 will have a motivated and skillful work force, using extensive communication, information and other technical aids, to create and profit from business opportunities. They will be in intense communication with customers, will be performing rapid and detailed analyses of proposed products and production lines, and will be in intense communication with suppliers and with other parts of the enterprise. This is a technology-intensive activity.

The successful competitor will not be able to allow its technology to lag far behind the competition, particularly in the key enabling subsystems supporting the manufacturing enterprise.

Total Enterprise Integration

Empowered individuals in mission-oriented teams will be the leading edge task forces of the successful manufacturing enterprise in 2006. Teams and individuals are part of an organization. Empowerment of teams and low-level functions to make decisions require that the decisions be coordinated across the company, otherwise unmanageable chaos and

disaster ensue. This coordination needs to be rapid, with much data passing to many people, and requires a high degree of analysis of implications, and decision support. This is achieved by total enterprise integration.

This can not be limited to integration of the technical systems only, but requires integration of work methods and procedures also.

Total enterprise integration requires a number of enabling subsystems in order to be achieved, including networks, distributed databases, open information systems, education and training systems, and more.

Vision-Based Leadership

Vision-led leadership establishes a clearly definable goal for people, achievable and exciting, establishes parameters which govern what is allowed and forbidden on the way to the goal, and shows the general direction. Vision-led leadership shows the goal and the direction to it, and motivates the work force to solve all the problems on the way to the goal.

As management hierarchies are reduced, and individuals and teams are empowered to make decisions and succeed in their mission, there will be no room for a manager to instruct exactly how a task is to be done.

The successful manufacturing enterprise of 2006 will be led by vision-based leaders who show the way and enthuse others to get involved and bring the enterprise to success.

Manufacturing Enterprise Elements

The following section provides descriptions for each of the enterprise elements, listed below.

- Business Environment
- Communication & Information
- Cooperation and Teaming Factors
- Enterprise Flexibility
- Enterprise-Wide Concurrency
- Environmental Enhancement
- Human Elements
- Subcontractor & Supplier Support
- Technology Deployment

BUSINESS ENVIRONMENT

DESCRIPTION

Manufacturing takes place in a business environment; the characteristics of the manufacturing process are governed by the business environment. The business environment is the major factor which impedes or facilitates development of new paradigm manufacturing systems. Supportive business metrics and procedures will bring agile manufacturing in ahead of the competition; inhibitory metrics will bring agile manufacturing in behind the competition, if the corporation survives.

The environment will be under constant evolution due to the pace of change and the internationalization of competition. While some business environment elements are not predictable or controllable, several key elements can be directed so as to provide strategic advantage.

Accounting and legal systems are important components of the business environment. Some elements of the accounting system are governed by company decision, for instance, cost accounting efforts. Other elements of accounting and legal systems are governed by standard practice which itself is changed by professional organizations in which companies are members and have some influence; while yet other practices are governed by government regulation and law.

The governmental infrastructure is clearly a major factor in facilitating or impeding development of business environment elements.

In addition to the government and other requirements external to a business, every business generates its own system of incentives, organizational regulations, and social attitudes of the workers. These factors are within the control of company management and play a major role in the efficient functioning of the enterprise.

WHY IT IS IMPORTANT

Very many books and reports have been published over the last decade giving examples of how different companies succeed in different ways because of the company culture. The business environment and the infrastructure support will have a marked effect on the behavior of the enterprise.

The competitive environment is now requiring that an enterprise be capable of quick reaction, and that it provide total quality. Further, many market opportunities can not be taken advantage of by a company working independently and there is a growing need for companies to be able to work together to take advantage of such opportunities. In the days of mass production when a product was static for a long time and when a production process was static for a long time, the business environment emphasized cost reduction and reliability of planning. Today's competitive environment requires that a business be capable of agily taking advantage of opportunities and this requires a business environment different than in the past. In the future, the pace of change and the demand for flexibility to compete in the marketplace will be even more than before. Business practices suited to the static world of long life cycle products, statis production and systems will hinder a company in the new competition.

CRITICAL COMPONENTS

Diversified Global Business Subsystems

The agile manufacturing of tomorrow will take place in a global environment. The agile enterprise will take advantage of market situations by creating many kinds of partnership and cooperative ventures in a diverse manner in many countries across the globe.

Enterprise Integration

The business metrics and practices in the agile enterprise will require rapid digestion of much information from across the enterprise and all of the partnerships that the enterprise is involved in. This will require enterprise-wide integration of the computer and information systems in order to gather that information rapidly and use it to analyze the business metrics required.

Performance Benchmarks and Metrics

People, teams and departments in companies behave according to the performance metrics by which they are judged. These current performance metrics do not emphasize characteristics needed for agile manufacturing and in fact are often counter-productive to that. In addition, performance metrics need to be benchmarked and compared across companies and in comparison with other countries.

Pre-Qualified Partnering Subsystems

In the world of agile manufacturing, opportunities will occur quickly and will require resources which a single corporation will not rapidly be able to put to work. Under such circumstances it will be necessary to quickly form cooperative mechanisms of many kinds of other companies. For that to happen, it will be necessary that companies be pre-qualified as to their suitability to partner in such enterprises.

Streamlined Legal Subsystems

In order for an agile manufacturing enterprise to react quickly and take advantage of market opportunities for competitive advantage, every component of the organization has to support that agile response. This clearly includes streamlining the legal procedures by which a company operates. There is a clear perception on the part of most professionals involved in manufacturing that legal subsystems, important as they are, inhibit agile response of the corporation.

Supportive Accounting Metrics

The accounting metrics on which a company operates are clearly major drivers in determining the behavior of the company. Accounting metrics currently are adapted to static mass production systems and do not facilitate the move to the agile manufacturing era.

Supportive Management and Organizational Practices
The move to agile manufacturing and the change in the business environment elements which give rise to agile manufacturing will clearly require great changes in management and organization in a company. These management and organizational subsystems should be supportive of the entrepreneurship and quick decisions needed to succeed in agile manufacturing.

COMMUNICATION AND INFORMATION

DESCRIPTION

This is the communication and information infrastructure which permits people and teams to interact rapidly across a large distributed company and between companies.

WHY IT IS IMPORTANT

Next generation manufacturing will be agile, or else will not be able to compete. Agility is gained by reducing hierarchic managerial control, setting up workers in teams and empowering them to make decisions. In a large organization or in a project of cooperating organizations these teams will need access to rapid and reliable communication and information systems to communicate and do their work. The communication and information infrastructure elements are the technical elements which are bringing into being the next industrial revolution. As such they are a critical and fundamental part of the change in the manufacturing system.

This is well illustrated by the changed method of operation of the Union Pacific Railroad over the past few years [266] (Complete reference notations for numbered references may be found in Appendix E). Until several years ago the railroad had many levels of management. Someone low down in the system who in fact had contact with a customer, and wanted to change the configuration of the train to be responsive to the customer had to send the request up through layers of management locally, regionally and nationally. By the time a reply came back with the authorization the customer was lost. This method of working was feasible in the old days of mass production when planning was done a long time ahead, where products were unchanging and where production runs were long. In today's world of constant change the agility required for an organization is simply not possible with many levels of hierarchy. The solution undertaken by the Union Pacific organization was to empower low-level employees, those personally in contact with the customers, to rapidly make decisions so as to be responsive to a customer's requirements. The Union Pacific Railroad is spread out geographically and has several hundred thousand cars in its system. Empowerment of low-level employees to make decisions as to configuration of trains and the use of railroad cars would have made the whole system impossible to manage if it were not coordinated in some way. The solution to that coordination problem is an enterprise integration control system. Making use of computers and communications the employee in contact with a customer gets into direct contact with a control center which manages the disposition of all the railroad cars everywhere. This is done by rapid computer communication and by voice communication. The integrated computer communication system enables the person interacting with the customer to coordinate rapidly with the central control organization, ensuring that the distributed decision making does not lead to a disorganized system.

CRITICAL COMPONENTS

Global Broadband Public Network
A Global Broadband Public Network is a high bandwidth network with wide access all around the U.S. capable of transmitting large amounts of data in a short time, reliably. This infrastructure is being put in place for considerations beyond manufacturing. Utilization of the network by manufacturing will be a fundamental part of the next generation manufacturing system. This is discussed separately.

Factory America Net
Factory America Net, described later, is an information system, intended to use the global broadband public network system and will enable people working in different companies to interact with each other and with information specific to their manufacturing needs, rapidly and efficiently.

Distributed Databases
Distributed databases are an integral part of the technology of the communication and information system as it works across many sites within one large corporation and between companies. This is discussed in detail later.

Evolving Standards
Efficient use of the communication and information infrastructure for manufacturing clearly depends on standards being available so that various systems from different companies can easily interact and exchange data one with another. Standards work is described in detail elsewhere.

Enterprise Integration Subsystems
Enterprise integration is the tying together of people in one and more organizations in order to rapidly make use of information so as to get work done quickly. This is discussed in detail elsewhere.

COOPERATION AND TEAMING FACTORS

DESCRIPTION

Cooperation elements are mechanisms which enable cooperation within and between companies and with other organizations such as, government, research institutes and universities. The organizations cooperate for mutual advantage. The mechanisms include technological tools such as computer networks which, if designed correctly, simplify interaction between individuals and teams, and organizational factors which facilitate or impede cooperation.

Each of the individual tools or factors is in itself subject to continuous improvement. The cooperation elements are therefore not a static set of factors but should be designed so as to be continuously improvable.

WHY IT IS IMPORTANT

No corporation has within all the resources available at short notice, to react to opportunities in a fast changing world. Cooperation is a critical key to the competitive advantage of an enterprise into the next century. The weakness of the United States in cooperation can be pointed out by the statistics given in the *World Competitiveness Report for 1991*. The U.S. ranks around 4 in the world in the number of patents per 100,000 people, in the total expenditure on R&D as a percent of the GDP and in the percent of R&D personnel in industry. The U.S. ranks 1 in the access business has to university R&D programs. U.S. ranks only 10 in the amount of cooperation between enterprises in R&D. This is a significant weakness in industrial cooperation relative to other nations.

Cooperation is important to deal with and the budget required to enhance this item relative to other R&D activities is minor. In particular, work is needed to deal with organizational and cultural impediments as well as to expand and improve technological tools using networks and computers for cooperation.

In the absence of significant tool building and enhancement and amelioration of the accompanying cultural and organizational impediments, setting up cooperation will continue to be slow and cumbersome. This would inhibit cooperation between individuals and groups, will dampen entrepreneurial energy and will diminish the fruits that entrepreneurship and cooperation could otherwise give.

The tools required are as much cultural and organizational as technological. There is no one silver bullet to solve this problem.

CRITICAL COMPONENTS

Empowered Industrial and Team Subsystems
Mission-oriented teams are organized not only to do what's instructed, but to use their initiative and group resources to define missions and solve problems.

Enterprise Integration Subsystems
Enterprise integration subsystems, using computers on a network to distribute and coordinate information all through an enterprise and a project, are a key technical mechanism for cooperation and teaming.

Factory America Net
The factory America net value-added industrial network will enable people in companies all around the country to post and read data regarding services and products, and to communicate regarding all manner of technical questions, problems and coordination.

Global Multi-Venturing Subsystems
Global multi-venturing, important today, will be much more important and pervasive in the age of agile manufacturing. Teaming and cooperation will be world-wide, cutting across national boundaries.

Groupware
Groupware is software which enables people to interact across a computer network and will be a key technology in facilitating cooperation and teaming.

Rapid Cooperation Subsystems
In the future, setting up a cooperative venture between companies, or setting up an inter-company team, will be rapidly advanced using standard techniques, rather than being a drawn-out, cumbersome process as it is today.

ENTERPRISE FLEXIBILITY

DESCRIPTION

Rapid realization and response in a continuous change environment will require an unprecedented flexibility in the composition and architecture of large systems of integrated hardware, software, and humans. The enterprise will be making continuous improvements on a daily basis, as well as major reconfigurations on a somewhat less frequent but equally sanguine basis, as product production requirements change and as new process technology and methodology become available.

This degree of flexibility is far beyond that which simply anticipates a range of expectations at the time the original system is designed and implemented. Inherent in this new flexibility is the capacity for rapid reconfiguration to accommodate the unanticipated, as well as the ability to make continuous incremental changes to operating production environments without incurring risk.

Changing a software system in today's enterprise is rarely allowed once it becomes part of the daily operating environment. Conventional wisdom knows that even simple changes can be expected to have unanticipated side effects that will put a production environment or information system out of commission for an indeterminate amount of time. This problem is so prevalent that people generally live with and work around bugs and problems in a software system rather then get them fixed. They'd rather live with the devil they know than the devil they don't.

Today's approaches to software systems and integration structures are a major impediment to the rapid response needs of the emerging enterprise. The successful enterprise must have the flexibility to alter its software systems on an as-needed when-needed basis without incurring any risk whatsoever.

This new degree of flexibility can be described as "agility". To accomplish this will require a completely different approach to the design and operation of integrated distributed software controlled systems and modular machinery, as well as a new approach to personal and organizational management.

Agility, however, requires more than just plasticity; it will also need localized decision making capacity. Agile systems must be able to make and implement quick decisions at the point of information. This links organization of the company with new technology available. The technology can no longer be dealt with independent of the people and organizational structure.

Currently, industrial organization in many companies is moving towards flexibility and reduction of management levels, but this change is only starting, with a long way to go.

WHY IT IS IMPORTANT

Enterprise flexibility elements are, in a nutshell, the elements which differentiate agile manufacturing from the old mass production system. The production system must be capable of constant change, to produce an unpredictable changing mix of product configurations as easily as a constant stream of product. That necessary condition is not enough. In order to take full competitive advantage of the production system, the whole enterprise should deal quickly with market opportunities, seeking markets, interacting with customers to define product configurations for the market, then realizing, producing, delivering and if necessary installing them quickly. A flexible production system within a slow-moving organization will give no advantage [148]. The whole enterprise must be flexible so as to take advantage of production flexibility to conquer markets.

Production hardware, even if flexible, is usually implemented as expensive installations, not as modularly constructed machinery. Technology and know-how to build the hardware modularly exist or are being developed. Implementation of this capability depends primarily on markets demanding the capability.

As flexibility increases into the realm of agile systems, most of the other identified infrastructural elements are affected. Specifically:

- Concurrency Elements
- Cooperation Elements
- Communication and Information Elements
- Human Elements
- Subcontractor/Supplier Support Elements
- Technology Deployment Elements

Each of these elements will gain a greater degree of freedom and expression as flexibility takes on agile qualities. This means that flexibility will be a pacing item for all of them.

CRITICAL COMPONENTS

Integration and Coordination Methodology Subsystems

As systems integration moves from an era of "interfacing things together" to a time of systems engineering, where architectures are planned for continuous change, we must develop an "Integration Technology". The objective is the construction and evolution of systems that are FIRM: flexible, improvable, robust, and maintainable, in a rapid change environment. Autonomous module concepts that are scalable from the "intelligent sensor" level to the workstation, the cell, the area, and even the plant, deal with issues such as localized scheduling, cooperation with other units toward shared higher goals, error detection and correction, robust alternative response to unsatisfied expections, human interaction, and more.

Intelligent Sensor Subsystems

The need for sensors increases in the agile manufacturing system as errors and decision-point conditions must be detected and responded to in real time without the need for human interaction. Many real time requirements are so short that the sensor must have "on-board" signal analysis and filtering capability so a critical condition is identified at the sensor level. In such cases we are asking the sensor to detect the existence of a problem rather than just send a continuous stream of measurements to a processor that is shared among many control functions.

Modular/Reconfigurable Process Hardware Subsystems

Modular hardware opens the door to affordable continuous upgrade and customization of processing and other production-related hardware. For instance, modular concepts are being investigated in the Air Force MMST project, for semiconductor processing equipment that allows self-contained stations within a multi-station machine to be configured, replaced, or reconfigured as appropriate. Changing such configurations may be done to accommodate a specific processing requirement, to utilize newer technology, or simply to fix a malfunctioning device instantly.

Software Prototyping/Productivity Subsystems

Designing, implementing, and testing complex software systems is a major unpredictable variable in the realization of a production facility. How long this will take, how much it will cost, and what it will be able to deliver in the end are unknowns until the effort is finished. Tools and methods are needed that facilitate software prototyping so that system design engineers can quickly reduce design concepts to operational models that can be validated and extended. Currently these designs are done on paper in the form of a systems specification written in a textual form. Design flaws are not uncovered until a considerable amount of resources have been expended in the implementation phase. Design flaws are the most expensive to correct and are often in the systems architecture itself which frequently precludes the attainment of the original system goals. Prototyping tools will execute design representations and expose flaws at an early stage when both the design and design effort are still plastic.

ENTERPRISE-WIDE CONCURRENCY

DESCRIPTION

A current focus today in most discreet-part manufacturing companies is to integrate the daily activities of product engineering and production-process engineering. The aim is to overlap these two activities so they are conducted in parallel at the same time, rather then in sequence one after the other. The object is to reduce the total time required to bring a new product to the market. But another important gain is also realized: a higher-quality, more producible product is designed because the product and process engineers share their knowledge as they work together. Today this team-work activity is referred to in some companies as simultaneous engineering and in others as concurrent engineering.

This concurrent activity concept can be broadened to encompass almost all aspects of the manufacturing enterprise. Though one might observe that traditional marketing, as well as even some sales activities, already occur concurrently with product design, the concurrency concept here refers to more than simply simultaneous occurrence: effective concurrency includes a tight interaction among cross-discipline work teams.

Third-party system integrators such as EDS, aerospace contractors such as Martin Marietta, and project engineering firms such as Bechtel, already employ some concurrency among their marketing, sales, finance, "product engineering" and "process engineering" functions in the course of bidding on competitive procurements. Though these may be called "service" firms today, how they (ideally) operate is very similar to tomorrow's agile manufacturing enterprise responding to a single-unit or short-run custom product requirement.

WHY IT IS IMPORTANT

In a rapid and continuous change competitive environment, agile manufacturing enterprises capable of taking custom orders, capitalizing quickly on new market opportunities, and countering competitors' strategies will necessarily practice broad-based concurrency.

In [73] it is observed that small companies and entrepreneurial companies exhibit the ability to move much faster than larger companies. It is suggested that this is because people in those companies responsible for marketing, sales, product engineering, production, and finance generally work within a few feet of each other. In effect, these companies practice a very real form of enterprise-wide concurrency.

Looking at the technology maturation cycle, there is much to be gained by broadening the concurrency concept beyond the product design and production areas. The process that moves technology from its laboratory feasibility demonstration to full commercialization includes time-consuming sequential steps in technology transfer, product conceptualization, market research, business planning, venture capitalization and prototype development.

With the gains of concurrent engineering already evident, it takes little imagination to see similar gains from broadening this concurrency concept to embrace all the enterprise.

CRITICAL SUCCESS FACTORS

Enterprise Integration

Enterprise Integration, as a broader application of the Computer Integrated Manufacturing (CIM) concept, promises to provide the coordinated functional structure and electronic communications infrastructure required for concurrency support. More importantly, it promises to "integrate" the enterprise; i.e., develop and enforce a unified information base and work methods throughout the enterprise that enables and promotes interactive activities between coordinated work functions.

Like CIM, Enterprise Integration is a large concept with many definitions and approaches. Unlike CIM, it is still a new concept, and comes at a time when the community is placing greater value on early standards.

Enterprise Integration will be largely a manifestation of software technologies - and especially integration methodology, applied to new ways of doing cooperative work. Most companies have seen the dependencies that large Management Information Systems (MIS) and even early CIM systems impose on the corporation. The agile enterprise of the future cannot exist with enterprise integration built upon existing software integration approaches. The enterprise integration enabling software in the agile manufacturing enterprise will be capable of safe, incremental, daily change; able to be radically reconfigured with out shutting down the company; and accommodating to entrenched legacy systems and subsequent migration strategies.

Factory America Net

Factory America Net (FAN) is a name used in this document to capture a concept. The concept begins as a value-added open computer network that provides electronic linkage among companies engaged in concurrent engineering activities. Thus, product engineers at a motor company might some day use FAN in order to interact with a machine tool supplier, a tool and die maker, and a custom controls company. Engineers in all four companies would form an on-line, interactive, multi-discipline design working together on a combination product-and-process design.

As concurrency broadens to encompass all enterprise activities, so does the nature of the network community and services. Resources from anywhere can participate without impeding the flow of information by physical travel. Network services go far beyond simple point-to-point connectivity with special databases cataloging the capabilities of companies participating in the network, training programs for small companies getting started on the network, information interchange standards, real-time interaction software, and more.

Representation Subsystems

Concurrency across multiple disciplines, and even multiple corporations, faces a formidable hurdle in the form of non-standard data and knowledge representations. IGES, PDES, and STEP are current standards activities aimed at providing common languages for describing the nature of manufactured parts. CALS is an initiative incorporating certain aspects of Electronic Data Interchange (EDI), and is concerned with standards for all manner of inter-corporate transaction exchange.

As pioneering attempts, these and other programs like them have shown by example the promise that a coherent data representation system could provide. But also as pioneers, these initial attempts have been focused narrowly and built upon early understandings. "Feature-based analysis" is gaining in popularity as a new way to describe part characteristics. Multiple varieties of data interchange are being forced upon small suppliers serving large manufacturers. For instance, in Detroit, each of the "Big Three" car companies has a different computer-aided-design (CAD) standard that it wants all of its suppliers to conform to - and many serve all three. This is inefficient.

Simulation and Modeling

Concurrency in its fastest form wants to know the effect of potential decisions and designs before the commitment is made for actual implementation. Cross-discipline teams are composed of specialists from a variety of areas who pool their individual talents in search of results beyond any single individual's knowledge. Computer simulation in each of the separate disciplines is important in order for an individual team member to ascertain the affect of a proposed course of action quickly - before other team members invest too much time and effort exploring paths that may be incompatible or have costly side effects.

Ideally, simulations specific to each of the enterprise functions would draw upon a common data representation of the enterprise operating characteristics. Simple as this sounds, herein lies one of the major hurdles to overcome. This difficulty comes to the forefront with attempts to model the enterprise. One would like the model to accept changes made in one discipline and reflect the consequences in all the others. Some of the difficulty lies in the area of data representations and the lack of standards. Less easily understood, however, are the bridges that span two seemingly unrelated representations - such as the static structural modeling captured by IDEF diagramming and the actual dynamic behaviors describable in state-transition diagrams.

All Cooperation Subsystems

Concurrent activities by their very nature require strong cooperative mechanisms and motivations. With concurrency meaning tightly coupled interaction across disciplines, concurrent activities by their very nature require strong

cooperation enablers and motivators. For a detailed exposition on Cooperation Subsystems the reader is referred to the section in this document devoted to the Cooperation Element.

Among other subsystems, the Cooperation Element calls for groupware, empowered individuals and teams, and rapid cooperation mechanisms. Groupware is computer-assistance technology that facilitates interactive and simultaneous group work using a communications network to connect people in different locations and working at different times - as such, it is a powerful part of the enabling infrastructure. Empowerment is necessary to the quick response required for a successful give-and-take interaction among cross-discipline teams. Rapid cooperation mechanisms remove bureaucratic and systemic impediments that preclude or slow down the process of cross-discipline and inter-corporate interaction.

All Technology Deployment Subsystems

Concurrent engineering today is often impeded by a mismatch of technical understanding and technology deployment between engineering and manufacturing entities - whether these entities are departments or divisions of the same company or in fact two different companies in a procurement/supplier relationship. Broadening the concurrency arena will bring parties with even greater differences to the same table. Propagating technology through these cross-discipline teams will be a challenge that impedes success until solved. The reader is referred to the Technology Deployment Element section for a detailed discussion of the subsystems.

ENVIRONMENTAL ENHANCEMENT

DESCRIPTION

Environmental standards are today usually perceived as being imposed by government, usually viewed as a burden on manufacturing. Environmental issues have become a critical factor for operating an enterprise. As society becomes more environment conscious, society and each citizen will not tolerate wasteful consumption of natural resources or environment contamination. Energy and environmental conservation and enhancement will be a natural, accepted part of good citizenship.

WHY IT IS IMPORTANT

Manufacturing processes developed today must bear in mind that a decade hence, lack of consideration of the environment will not be tolerated. The manufacturing sector will conform with the demand of the society to meet the needs of the present without compromising the ability of future generations to meet their own needs. Organizational structures, process, systems and equipment are being adapted to transform companies to "environmentally safe" organizations.

The fact that relatively few words are used on this page for this subject is not an indication that this is not important; it is an indication that this is already today accepted as obviously true.

CRITICAL SUCCESS FACTORS

Key subsystems required to support environment enhancement include:

- Energy Conservation
- Waste Management and Elimination
- Zero-Accident Methodology

Each is explained in some detail elsewhere in the report.

HUMAN ELEMENTS

DESCRIPTION

In a company based around a mass-production line where the product is unchanged over a long period of time, the worker can have no influence over the product or the production method. A salesman cannot change a product to suit a customer; he can only sell more of a fixed product. A production line worker cannot change any part of the mass production line; all he can do is not fall behind in doing his tasks.

The world of agile manufacturing is diametrically opposite the world of mass production. An enterprising salesman can offer a customer a special configuration of a product; an enterprising production worker can figure out ways to improve the production; anyone in the whole enterprise can figure out ways to save time and be otherwise responsive to customers' desires. There is, therefore, a growing realization that the people who work for an enterprise and the skills and motivation they collectively bring to it are its most important asset. As such they are to be nurtured, not seen as simply an operating expense.

Employees work well when they understand the measurement system applied to their performance, and when they understand their task and how it contributes to the success of the company. Performance measures and standards and continually informing employees of the goals of an organization will improve accordingly.

People will more and more work in multifunctional teams. Within the bounds of their mission statements, each team will be self-managed and regulated. An employee will operate both as an individual and as a member of a team: any one employee may be a member of several teams simultaneously. The enterprise will give individuals and teams of individuals the power to make various entrepreneurial decisions about their projects, within the context of a company policy which encourages entrepreneurship.

WHY IT IS IMPORTANT

The components of flexible and modular production systems will in most cases be inexpensive enough that most companies will be able to install them. Competition on the basis of the installed production process components will have no relative advantage. Competitive advantage will be obtained by people finding markets and opportunities for product sales and
by people finding novel and beneficial ways to use the flexible modular production systems. Competitive advantage will therefore be obtained by the ability of the people in the enterprise much more than by the machines in the enterprise.

It should also be noted that, more and more, a major component of a product is knowledge, not material. For instance, in a semiconductor 3% of the cost is material -the rest is knowledge. Almost all the knowledge in the product is from the heads of the marketeers, designers and producers of that product. This human asset needs constant nurturing.

In the world of agile manufacturing, cooperation will be a part of daily business. The emerging need for cooperation in corporations, and for partnerships and strategic relationships is becoming clear. This places a premium on trust and honesty in business relationships, which in turn depends directly on that of its employees.

CRITICAL COMPONENTS

Continuous Education and Training

This will not only deal with use of new machines and systems in the enterprise, but will constantly broaden the horizons of all workers. Rapid inter-company and world-wide venturing will become common; as a result, general education of workers so as to easily relate to workers from other companies and countries will be important. Also, general scientific and technical education enable workers to deal better with unforseen problems and new technologies, and will also be part of the continuous educational process.

Customer Interactive Systems

Customers, dealers and stores will more and more be dealing with computer interactive systems to configure and order items. These systems need obviously be designed for easy use, and to present uniform interfaces to customers.

Empowered Individual and Team Subsystems

In the agile enterprise, individuals operate in mission-oriented teams, empowered and motivated to show initiative in pursuing advantage for their company. This requires an infrastructural subsystem to encourage such operation.

All the subsystems of the agile enterprise will create an organization exhibiting a people-nurturing culture and environment; measurement and reward systems which are easy
to understand and reward both individual and team achievements; compensation which is intellectual and emotional as well as financial; a business environment which engenders trust and motivates employees to work for the success of the company over the long term; and technological tools to facilitate cooperation and initiative by the employees.

SUBCONTRACTOR/SUPPLIER SUPPORT ELEMENTS

DESCRIPTION

The 360,000 manufacturing firms in the U.S. with less than 500 workers, account for 46% of the national industrial production. For these companies, 80% of their output is fed into other companies. This considerable resource is a kingpin of national manufacturing.

Next generation manufacturing will be agile, of high quality. It will be networked-based manufacturing, where the speed of response will often be dictated by the accessibility of the correct information at the correct place at the correct time. This new world of manufacturing will require not only suitable technological systems, but also individual skills and organizational structures to respond as needed.

The subcontractor and supplier community abounds with entrepreneurial, capable, technically smart people. However, businesses of small and medium size do not have the financial resources to hire and set aside people to deal with the many technical problems of networks, computer systems, distributed data bases, global dictionaries and the like, as well as work force training, total quality maintenance systems, and planning evolving restructure of the company.

WHY IT IS IMPORTANT

Experience has proven that instability inherent in small companies can be dealt with by cooperation among them. The result is an efficient and flexible enterprise constituting a collection of small companies. A well-known example is the networking of small companies in the Silicon Valley; they

showed outstanding growth (40-50%) when large organizations were having problems [305].

The current support structure to help small business over these hurdles is insufficient.

The existing programs and technology transfer centers are far too few for the quantity of companies involved. Commercial consulting on these issues, is usually too expensive for small businesses. There is a great need for learning and technology transfer of all kinds, for subcontractor/supplier support. Books, video tapes, multimedia classes, lecturers and teachers with material for the trainers are all greatly needed.

Introduction of network-based technology is not simply a process of installing new systems within a given framework. It requires a change in individual skills and in functional structure. This, in turn, requires a high level of education and advice. A very approximate estimate can be made for the effort required assuming that technology and training tools exist. If we assume a low figure of one person-month of effort per company, to have small and medium manufacturing businesses integrate into the world of network-based manufacturing, the effort needed will be 30,000 person years. If spread over the next decade, this will be a considerable effort of 3000 man-years per year.

CRITICAL COMPONENTS

Empowered Individual and Team Subsystems

Suppliers will more and more be brought into their customers' teams for various projects. They will more and more require decision-making ability and initiative on the part of their workers, so as to be a constructive team member and a valued supplier.

Enterprise Integration Subsystems

As large enterprises establish enterprise integration systems, a supplier not part of that system will be cut off from customers. This may be a difficult problem to the extent that different customers establish different enterprise integration systems, requiring the supplier to install different systems for each, with attendant training and operational problems.

Factory America Net

The Factory America Net will have information about goods and services available and wanted, around the country, and will provide a means for companies to provide cooperative offers. It will be important for a supplier to be part of this network.

Global Multi-Venturing Subsystems

As more and more global multi-venturing opportunities open up, a supplier should want to be a recognized component of that global multi-venturing community.

Groupware Systems

Groupware is software enabling cooperative interactive work on a computer network. This will be one of the tools used by a supplier as he interacts with customers and partnering companies.

Rapid Cooperation Mechanisms

Cooperative ventures will rapidly be set up and dismantled, and the supplier will see to it that he is capable of being a part of such venturing.

Continuous Education and Training

The workers in the supplier company will continuously be educated so as to make them effective contributors to competitive opportunities for the company.

Human-Technology Interface Subsystems

As suppliers become part of an electronically networked infrastructure, the human-machine interfaces will clearly become part of their daily working life. These interfaces will need to be designed not only for big industrial corporations, but for suppliers of all sizes.

Knowledge-Based Software Systems

Knowledge-based software systems give the possibility of encoding various kinds of knowledge in a format and process which is easy to use, and which can train and educate individuals in the new technologies, methods and organizational structures needed.

Technology Adaptation and Transfer Subsystems

As the rate of technology transfer increases it will be important that a supplier not drop behind its competitors and the needs of its customers. Technology transfer to supplier companies will need to be facilitated.

Evolving Standards Subsystems

Standards will continuously be evolving, and since suppliers will be part of the networked industrial system, these will impact them. This is not a straightforward situation, since suppliers will not usually have sufficient manpower resource to devote to learning, and integrating up-to-date standards.

TECHNOLOGY DEPLOYMENT ELEMENTS

DESCRIPTION

The rate at which new technology and methods becomes available continues to accelerate, far outstripping adoption and utilization rates. Technology transfer activities have been the focus of much attention in the last few years but none appear to be overly successful in speeding up the process of adoption.

Until technology deployment is mastered as well as technology development, the U.S. will remain many steps behind its potential for cost reduced products and fast response enterprises.

Numeric controlled machine tools are a good manufacturing example. Capability was demonstrated first in 1958, and the concept was relatively mature in 1965. Yet in 1990 only 20% of the appropriate machines in the U.S. make use of this technology. In contrast, the Europeans were estimated at 30%-35% and the Japanese at 65%. This contrast may have nothing to do with adoption processes rooted in cultural or ethnic differences, and may simply be a function of the rebuilding after WWII that went on in Europe and Japan. But no one really knows.

WHY IT IS IMPORTANT

This is where large cost-reduction opportunities exist in two key areas: eliminating the large hidden costs associated with the inefficient deployment processes that currently exist, and in hastening the utilization of lower cost manufacturing processes and methods as they are developed.

Hidden costs associated with failed or slow adoption and evaluation processes generally appear in the overhead category. Here are costs of protracted investigation, testing, justifying and selling, as well as costs associated with all of those exercises that never became deployed.

It may be that the more important costs are associated with lost opportunity rather then cost reduction. Cost reduction assumes an ongoing enterprise. However, in an unforgiving climate of global competition and rapid technological change, failure to adopt certain key technologies in a timely manner results in irrevocably lost markets - which for many enterprises can result in lack of business viability.

As the technological pace quickens, a company's ability to evaluate and deploy appropriate technology will be a critical factor in its ability to survive.

CRITICAL SUCCESS FACTORS

Technology Adoption and Transfer Subsystems

The impediments and processes of technology adoption must be understood at the point where it counts the most: the human being; and at the time it counts the most: that first decision to deal honestly with something new. One cannot hope to accelerate these processes until their underlying details are understood. Adoption and transfer attained today comes with little systematic effort.

At one time man fed himself by hunting and gathering foods that he managed to stumble upon. Eventually he learned how to cultivate and nurture the growing of edible plants and animals. "Successes" in technology adoption today are, for the most part, stumbled upon. It's time to learn how to cultivate and nurture.

Human/Technology Interface Subsystems

One of the largest impediments to technology adoption is the lack of standard human/technology interfaces. Two examples we are all familiar with include the many different approaches to home VCR programming and the multiple approaches to setting digital clocks and watches.

In a rapid change environment where new, improved, and alternate technologies are continuously offering benefits over the ones already in place, the necessity to learn a new interface erects both human-emotional and corporate-cost barriers.

A body of solution approaches already exists on the conceptual level. Though little has been started toward standardizing human/technology interfacing, strong developments are underway in the area of standard technology/technology interfaces. For instance, the "common API" (application program interface) known as POSIX will allow an application program, such as a factory scheduling program, to work on top of a variety of operating systems, such as VMS, UNIX, and OS/2. The POSIX implementation for each operating system then translates the common interface into the idiosyncrasies of each operating systems. Thus, as new operating systems or better implementations of these operating systems become available, the application program can take advantage of them without change.

An analog in the human/technology area is the approach to the VCR programming problem recently introduced in the form of a hand-held universal remote programmer. This clever device provides a single uniform interface to the user, and learns the individual idiosyncrasies of each device it is to control.

Continuous Education Subsystems

Competitive pressure in a rapid change environment will require that companies introduce new methods and technologies on a continuous basis. Companies that fall too far behind best-practice potential will quickly be competing

with others that have decisive advantages. The enterprise that takes advantage of the continuous change environment will have people who are capable of utilizing advantageous methods and technologies as soon as they become appropriate - whether to simply maintain competitive parity or to favorably change the competitive balance.

Aside from making a timely decision and committing the necessary funds, deploying technology effectively is wholly dependant upon learning activities, learning activities that don't begin until a willingness and desire to learn is present in the people who will be involved. The master keys to opening these doors of "willingness" and "desire" have not yet been found.

Two specific areas of technology are important enough to warrant mention here:

- Intelligent Human-Learning Interface Technology

Artificial intelligence has an important role to play in the education process. Technology that interfaces teaching software to the learner and understands when to speed up, when to skip over, and when to go deep in the teaching process will make a difference in learning speed and quality. Technology that can answer questions rather then present a programmed sequence of material will let people learn in their own idiosyncratic styles the things they want to learn when they are ready to learn them. Technology that comes to understand what the learner knows already will present new material in a more acceptable and efficient way.

- Personal Simulation Workstation Technology

Teaching-workstation technology can go far to speed up the learning process and make learning an enjoyable and natural activity. Video is a useful but passive teaching aid. Interactive video is more useful but still remote and artificial to the user. Real experience is recognized as the best teacher.

Simulation as a way to replace real experience is used in many of our other business activities, and in fact has some history in teaching and learning. War games are one example.

Virtual Reality is the name given to a new form of simulation. Unlike the simulations we are familiar with today, where information about simulated results are presented to us as tabular data or on-screen animated graphics, virtual reality puts the user into the simulation as a participant, and erases the sense of simulation completely. Virtual reality technologies include such clumsy things today as video goggles, sensor-wired body-suits, and super-computers that control a total visual environment changing in perspective as the person moves in that artificial space. If suitably programmed, a very real-seeming ride might be taken on a semi conductor wafer as it goes through its entire fabrication sequence, or an exploratory walk may be taken with impunity through a hazardous processing environment.

Knowledge-Based Intelligence Subsystems

Knowledge-based subsystems are extremely important in the capture, reduction, packaging, expression, and dissemination of the knowledge utilized in operating a manufacturing enterprise. Capturing, reducing, and packaging the widely dispersed knowledge that is responsible for the activities currently performed in successful manufacturing enterprises is sometimes referred to as "systematization".

A great deal of effort must be expended in this systematization effort before we can begin the process of transferring this knowledge to others. In addition to transferring knowledge that has been systematized, we would like to package this knowledge in "knowledge-based" artificial intelligence modules that can assist a human in decision and operation activities.

Some knowledge-based artificial intelligence modules referred to as autonomous agents are capable of expressing this captured knowledge while independently carrying out a set of activities. For example, an appropriate "personal agent" might be directed to interface a person to information and equipment, and even act on that person's behalf according to instructions. It would present a common and familiar face to the person regardless of what it is responsible for accessing and directing on the other side. It can be instructed to notify the person when certain conditions exist or certain events have occurred. It can be asked to present graphical information that is gleaned from databases or activities-in-process, without the person having to understand where any of the information comes from or how the information is obtained and transformed into the presented form. It is a general purpose, constant, interface to all manner of changing technologies on the other side.

Implied Enabling Sub-Systems

The following section describes each of the items listed in the table below.

- Continuous Education and Training
- Customer Interactive Systems
- Distributed Databases
- Empowered Individuals & Teams
- Energy Conservation
- Enterprise Integration
- Evolving Standards
- Factory America Net
- Global Broadband Networks
- Global Dynamic Multi-Venturing
- Groupware
- Human-Technology Interface
- Integration Methodology
- Intelligent Control
- Intelligent Sensors
- Knowledge-Based Artificial Intelligence Systems
- Modular Reconfigurable Process Hardware
- Organizational Practices
- Performance Metrics and Benchmarks
- Pre-Qualified Partnering
- Rapid Cooperation Mechanisms
- Representation Methods
- Simulation & Modeling
- Software Prototyping & Productivity
- Streamlined Legal Systems
- Supportive Accounting Metrics
- Technology Adaption & Transfer
- Waste Management & Elimination
- Zero-Accident Methodology

CONTINUOUS EDUCATION AND TRAINING

DESCRIPTION

Few corporate activities will be as important to the financial well-being of the entity in terms of its ability to compete. A high priority will be placed upon the ability to enhance the range of products the company can create and deliver. This agile manufacturing environment will demand an agile work force, capable of shifting job descriptions and skills as the situation warrants. Not only will the worker be familiar with his company's product line, but in the partnering atmosphere of tomorrow's corporations, he or she may be called upon to provide expertise in skills that vary substantially from those to which he has been accustomed.

Only training and education can provide the impetus for a company to move in versatile directions. Competitive advantage will accrue to the company that is able to adapt rapidly to new technologies, to the speed with which information is assimilated, and to the call for flexibility in manufacturing skills. Only education and training will elevate the skill and knowledge levels of the current labor pool, and this labor pool includes all categories from the typical blue collar "touch" laborer through engineers and senior management. All will need to be attuned to the non-static character of their work environment. Additionally the range of markets within which an enterprise can compete will be broadened and enhanced by its work force acquiring knowledge and training in critical areas. These may be foreign (non-North American) markets, or they may be products foreign to the particular factory floor, as in the example of an armored personnel carrier manufacturer entering the truck market.

Education and training are the only reliable means of coping with the culture shock of transforming our current relatively fixed production mechanisms into the agile systems the future requires.

The problem of educating a difficult to train, usually aging, work force does not currently have a solution. This large body of people needs to be brought in to the education and training environment. Solutions to this are not yet clear.

Continuous education and training is today a large activity. In 1988, U.S. business spent around $30 billion to provide 17.6 million formal development and training courses.

WHY IT IS IMPORTANT

In a very real sense, education and training of the work force are today so important, because for so long they have been considered unimportant. In the classic manufacturing assembly line scenario, specialization was the key factor in employee utility. The work force was attuned to the importance of performing one job expertly. Once the job was learned and the product component or assembly line service accommodated, expertise had been achieved and learning was no longer as important.

The key to employee utility is versatility and willingness to adapt to rapid change in products; in job description; in skill required; in knowledge to facilitate change; and ability to cope temperamentally with an agile environment. While the skill level of an employee will not necessarily degrade, the skill level required of the future employee will increase. There will be no comfort level achieved by the predictability of performing the same job one did the day before. Quite the opposite, the discomfort which accompanies constant change, unchecked by additional training, will lead to performance degradation and employee turnover. One of the key components that leading companies are embracing today is that of addressing functional illiteracy in their work force. Instead of assuming that all people with a high school education are at the same level and all that they need is some additional training, companies are spending time on non-punitive testing and providing education to make their people functionally literate first. This is critical if additional training is to be fully utilized and the fear of change is to be overcome.

It becomes apparent then that education and training are the factors counterbalancing the potential frustration and anxiety of a constantly shifting environment. And for an enterprise to make significant improvements in its competitive capabilities, comprehensive education and training programs will be essential. Enhanced performance at the job notwithstanding, historically training and education were considered benefits to the employee, tools to serve his welfare, opportunities for him to better his future. Whatever the consideration, they were not viewed as critical components of the enterprise's ability to compete. Hence, training and education was haphazard, the budget spare, the attention slight, and the priority low.

In a larger sense, contemporaneous education and training in the future will be orders of magnitude more significant than they are now. In addition, the rapidity of technological innovation will force more education and more training just to stay abreast of improvement in design and methodology. Whereas today, one company's present poorly trained work force will impact the fortunes of only that company, tomorrow's untrained employees will negatively impact another company's product in ubiquitous joint ventures - an extension of the domino effect.

The cost of developing curricula, skill profiles for various jobs, developing media based education, organizing and executing education and training is potentially enormous. For this reason alone, training and education are in the category of generic non-competitive endeavors which have common sources, common manifestations and common cures; thus they represent significant opportunities for cooperative burden sharing.

CRITICAL COMPONENTS

That education and training is critical to future manufacturing is not at issue. However, defining and developing an effective agenda that will address the needs of competitiveness in a flexible environment is a trickier question, as is leveraging the resources available between and among partnering entities. For instance how would the Department of Defense interact with a private company with respect to paying for education and training for anticipated projects. And how would these factors impact "quick reaction."

Constraints in the collective longaining process are today all too often an inhibitor to extending education and training; these need to be overcome.

This would call for a full understanding of how to take advantage of cooperative efforts and achieve competitive advantages for each partnering enterprise. This means that education and training are viewed as critical components of competitive advantage, just as is adaptability, shortened product development time, and quick response to customer demands. In fact the cornerstone of preparation will be the knowledgeable work force.

There will be a call for "special" educators to handle the cultural problems of new versatility requirements of the manufacturing company. The key to achieving this is the organization of a well delineated program which partners educational and corporate personnel in an integrated solution, and leverages the investment equitably.

Technology will be more and more prominent in the continuous education process, using multi-media, video displays, and the like. Employee incentive and reward systems which encourage education and training, are important components, required to motivate workers to the effort required.

CUSTOMER INTERACTIVE SYSTEMS

DESCRIPTION

In a truly integrated customer-pull business environment, the customer, or his representative, who may be a dealer, or a store assistant, engineer or purchasing agent must be able to directly specify requirements without the intervention of intermediary entities such as a sales-person or sales engineer. The level of interaction could be from specifying from a standard catalog up to the level of new design specifications.

Such systems are currently very uncommon.

WHY IT IS IMPORTANT

Currently, it is estimated that 20% to 30% increase in profit margins can be achieved by involving customers in a product's design [267]. Some companies have already started to move in that direction -- Augat Inc., a manufacturer of connectors for integrated circuits, has developed a system that allows customers (linked via modem) to download CAD drawings together with text describing what they want, and choose their connectors interactively. It is also important for the satisfaction of "prosumers", that is, consumers that not only consider what is offered to them but also specify a product configuration according to their own desires. The systems may be operated by the end consumer, or by a dealer or information broker who represents her/him. The system will be similar in any event.

CRITICAL COMPONENTS

Related Subsystems

- Enterprise Integration
- Factory America Net
- Global Broadband Networks
- Groupware
- Human-Technology Interface
- Knowledge-Based Systems
- Representation Methods
- Simulators & Modeling
- Total Enterprise Integration

All the above will lead to networked-based industry and commerce, within which customer interactive systems will find a natural place.

DISTRIBUTED DATABASES

DESCRIPTION

Distributed database systems (DDBS) may be defined as integrated database systems composed of heterogeneous autonomous local databases geographically distributed and interconnected by a computer network.

The distributed architecture allows the following:

- Increased flexibility of the system resulting from its modular and open structure which allows growth and smoother change of functions and capacity;
- Increased data security due to better protection in case of hardware and software failures or attempts to destroy data [62];
- Better system performance as a consequence of increased level of parallel processing, also obtained by bringing the system resources closer to data sources and users; and,
- Holding data on different computers at different sites, with critical data replicated or frequently backed up, is less susceptible to catastrophic failure of an entire system, than keeping data on one large mainframe computer.

WHY IT IS IMPORTANT

Distributed computer systems are the "lifeblood" of the cooperating modern enterprise. Different parts of one or more organizations have different databases which must begin to work together.

The evolution of computer technology has lowered the relative cost of computing versus communications and has provided high speed local area networks. Even for one organization it is often worth constructing a distributed system in which computers interchange computation results between them via communication links instead of installing one large mainframe in which data is gathered via communication links. In distributed systems individual processes can be dedicated to particular functions of the system leading to the elimination of very complex multiprogramming software usually associated with large mainframes. On the other hand, coordination of data on the network is much more complex than for a centralized mainframe database.

In manufacturing, a major U.S. plant reported a reduction of design time from 52 to 26 weeks, a reduction in direct labor cost by 70% and improved time-to-market by 35% using distributed databases for design and manufacturing. This allowed the design data to be available to all parts of the company faster. However, the spokesman for the company revealed that convincing management of the need for DDBS took three years. The cultural problems were indeed prominent [87].

CRITICAL COMPONENTS

Architectural Models

The current, undistributed database technology is based on theoretical models of database architecture. This scientific basis is fundamental to the success of databases. Generally accepted scientific based standard meta-models for a federation of heterogeneous distributed databases do not yet exist, but if developed will be of critical importance.

Global Catalog

This data dictionary tells which database fragments are found on which physical nodes and where the nodes are located. The catalog also stores information on how the database is partitioned and defines parameters like syntax, fields, records, tables and the relationships between them. The cultural and human issues involved in getting people to agree on attribute names and meanings are extremely difficult. This needs strong high-level pressure and ongoing commitment and determination from management [62], together with software tools for integration and coordination of databases.

User Interface

The DDBS is managed by a distributed database management system whose main task is to give users a transparent view of the distributed structure of the database, i.e. the illusion of having a monolithic and centralized database at their disposal. The interface should be the same all over the system.

Coherency Control

This deals with ensuring that similar or related data, held in different places in a heterogenous federation of databases, is coherent and consistent. An obvious additional requirement is to minimize overhead and transaction response time, and to maximize DDBS throughput.

Communications

Technological advances in communication systems aided the DDBS. High data bandwidth necessary for the performance of distributed database systems can be attained by FDDI (the Fiber Distributed Data Interface). The low cost buses, token rings, ethernet and FDDI networks enabled reliable physical interconnections.

Distributed Data Strategy

The most important element in distributing data is to have a distributed data strategy. This will help to ensure overall data accessibility, optimize response time and productivity, minimize network costs, and facilitate system and data administration. Other important considerations include the near- and long-term requirements for data and the need to understand the key relationship among key variables such as data availability, security, reliability, performance, processor usage, data storage media, and communications/network use and cost.

Current capability is characterized by a number of shortcomings and difficulties.

- Currently, the software embedded in higher layers of the international ISO OSI communication model limit the communication capabilities in distributed database applications. For example, significant data rate performance losses occur in the OSI communications models. A throughput of less than 1 Mbit/s is obtained at the database level, in FDDI communications of hundreds of Mbit/s intrinsic rate, due to such software losses [303].
- In the future, increasing number of geographically dispersed private and public organizations will be service providers. Future data in distributed environments will be not limited to text only but image, motion video, graphic and audio. The size of databases to store this information will be massive. For example, 5 sec high resolution motion video at 30 frames/sec. requires 3800 Mbit/sec. compared 8.5x11 ASCII page which is 0.011 Mbit/sec. Current data compression technology allows only 3:1 compression without loss. Greater compression ratio of 12:1 can be achieved only with loss of information that can lead to image degradation. The sizes indicate that there is a need for massive data storage and high bandwidth communication with respect to distributed database technology. Presently, there is little knowledge of how to share such diverse types of data in large-scale distributed system [303].
- As distributed systems grow, they tend to be more heterogenous. Problems of heterogeneity are difficult because of the presence of multiple computational environments, each with its own notations of file naming and functionality, which will be a chronic problem. The problems such as salability, security and availability will continue to be important as distributed file systems grow in size [303].
- A survey of 100 information system sites in Fortune 1000 financial services and insurance companies finds reports that the number of distributed databases in the U.S. is expected to grow from 25 in 1983 to 1800 by 1993. The distributed database software market will be worth billions by 1993. The revenue from distributed database software grew from $150 million in 1988 to over $1.2 billion by 1993 [308].
- Currently, there are many central databases. As distributed database become technology of the future, the existing databases should have distributed access capabilities. The problem of data translation can arise. Even though

connectivity can be attained using gateways, the data restructuring methodologies should be easy and fast. This is an enormous problem. One industry expert predicts that the distributed databases won't be commonplace until about 2050 [133].

- Fully distributed databases will be facilitated in the future since microcomputers are fast enough and big enough to do the work. In a recent experiment the fastest 486 PC did 29.9 transactions/sec, comparable to a workstation which did 25.8 transactions/sec. Using an optical disk, a PC can store up to 5000 Mb data [133].
- Today's user interfaces to databases have very limited capabilities, especially in dealing with multimedia applications [197].
- With respect to Query languages, there is a need for standardization. The SQL Access Group is trying to accelerate standards for retrieval and update of information from heterogenous databases. Proprietary solutions exist for these functions, but the number of databases these solutions can talk to is limited. The Remote Data Access (RDA) protocol committee of ANSI is in the process of developing standards for client applications to remote data servers. RDA will be implemented as an OSI application layer protocol [198].

EMPOWERED INDIVIDUALS AND TEAMS

DESCRIPTION

A team is a relatively small, self-managed and empowered, group of people with a defined team goal. Its members may be from different parts of the organization such that the team can deal with all aspects of a project. Teams are usually small to reduce communication problems and exclude members whose areas of responsibility are peripheral to the team task. They are self-managing and empowered to act such that delays caused by referring decisions back up the line are minimized. Finally, teams should be multi-functional to be most effective because the knowledge of every member is leveraged by the knowledge of the others resulting in a comprehensive solution to problems, from the beginning, in a parallel fashion.

A dramatic shift in both structure and business philosophy is required to reshape a traditional hierarchical structure of 7-8 levels to a flatter structure with less levels. This transition is aided by minimizing the requirements for specialists in all functions, and moving to more generalists who are capable of performing multi-disciplines. The organization's information and communication techniques become common throughout the organization and transportable between other business events. Organizational barriers and the constant desire to form special committees decreases as the new environment depicts less internal boundaries, thereby promoting a more responsive, cohesive unit to address pressing concerns and issues. The new environment removes traditional labeled and pigeonholed specialists who tend to become stagnant and complacent; it encourages multi-discipline ability leading to increased flexibility to react to challenges and opportunities.

Concurrent with this new environment is a notable improvement in employee utilization. This occurs because of the infrastructure established between companies which focuses on optimizing the applications of each employee's skills. This sharing of skills and work force helps reduce overhead labor, enabling companies to be more responsive to dramatic peaks and valleys in demand with limited resources.

As the technology enables more highly automated methods of designing, planning for and building products, the role of a broader range of employees consists of "change" oriented activity (new designs, new processes).

A recent survey of books on the subject [180] states that no more than 10% of the American work force is organized as teams, but a survey shows that executives expect that by 1996 50% of jobs will have a team format.

An interesting example of the dramatic impact of empowerment is the Toyota organization. In 1951 workers made 0.1 suggestions for improvement per worker, of which 23% were implemented. In 1986 they made 47.7 suggestions per worker of which 96% were implemented. Each suggestion evokes some response within 24 hours.

WHY IT IS IMPORTANT

Empowering individuals and teams is important because it reduces the company's new product development time, response time to a customer, and improves product quality. It also enables effective concurrent engineering. From the performance evaluation standpoint, the team approach substitutes collaboration for auditing. The success of companies that implement the team approach in process improvement and quality projects can be illustrated by the experience at Miliken, now a Baldrige Award winner. Thousands of projects were completed by teams at Miliken [172]. A multibillion dollar aerospace company was able to reduce its development time for major products from 36 to 24 months. The responsible team constituted members from engineering, manufacturing, quality assurance, and product support [90].

CRITICAL COMPONENTS

Management Style

To enable the empowering of the teams, senior managers concentrate on improving the system and delegating routine operating decisions to others. Business responsibility is placed as far down the organization as possible. As reported by Bower and Hout [46], a bank reduced the time to process a loan from several days to 30 minutes; formerly the applications needed the approval of a series of supervisors; today the loan application comes to a single team formed by a credit analyst, an experienced collateral appraiser, and bank procedures expert, such that the approval can be made almost at once.

Performance Measures

They should reflect the fact that putting together a successful team often means broadening the scope of individual jobs and organizing the team around market-oriented purposes rather than departmentally defined tasks. The experience of one company in this study showed a dramatic improvement in team performance, for all metrics used, regardless of how a team was organized.

Continuous Education and Training

Team members learn more about the work process through communication and close working relations with peers with different expertise. However, they also learn about customers, competitors, and the company's operation; traditionally, the latter issues were considered by top managers only. Therefore, rapid feedback loops become standard practice. An example is Benetton, which collects data daily at the retail level such that teams know what is selling and what is not [46]. At Du Pont, production workers visit customers just as sales people and product engineers do to learn their needs firsthand. Finally, members must keep up to date on the leading edge of knowledge and technology. Milliken, for example, spent $1,900 per employee for training during 1989 [172].

Resources, Communication and Structure

This people development process which enables complex tasks to be executed by a small number of well rounded generalists, also brings together the necessary resources and makes the required decisions to bring about the new product or process. If the core team grows too large, the project becomes unmanageable.

Technology exists to allow instantaneous and complete communication of all critical product and business data to all parties. (See Enterprise Integration in this volume.)

Flexible and reconfigurable organizational structures, defined and supported by enlightened functional management, contribute to the success of empowered teams.

ENERGY CONSERVATION

DESCRIPTION

Industrial processes consume approximately two fifths of the developed world's energy [294]. Energy is a critical public-policy issue. It is vital to America's future standard of living and industrial competitiveness. Population expansion with ever better standards of living cause higher global consumption of energy and raises concerns over energy conservation [206]. In the U.S., the average per capita energy consumption in 1989 was approximately 325,000 Btu with estimated decline of 7% from 1979 [226].

According to the World Competitive Report [392], the U.S. ranked 16 among 23 industrialized countries in terms of being most likely to be vulnerable to shortages in critical imported resources. Domestic oil demand, which had fallen to 15.7 million barrels a day in 1985, climbed to 17 million in 1990. Meanwhile, domestic production has been declining; aging U.S. oil fields produced only 7.2 million barrels a day in 1990, down from 8.9 million in 1985. As a result, the U.S., the world's largest energy consumer, now imports more than 50% of its crude-oil and petroleum products. Fully one third comes from the politically volatile Middle East. It is estimated that on its present course, the U.S. will need to import two-thirds of its oil by the year 2000 [226].

WHY IT IS IMPORTANT

Awareness of energy requirements and awareness of the environmental effects of energy use are high in the consciousness of informed citizens. Industry, as a user of two-fifths of this energy, is a key component of this major public concern.

CRITICAL SUCCESS FACTORS

Efficient Use of Energy

The U.S. has made progress in energy efficiency. From 1979 to 1989, the amount of energy consumption per Gross National Product (GNP) declined 20% - from 25,000 to 20,000 Btu. Energy consumption per capita meanwhile fell nearly 7% - from 349,000 to 325,000 Btu. Industry has led the way, trimming its energy demand 17% (from 23 trillion Btu to 19 trillion Btu) during the same period [226].

Efficient use of energy in industry was made possible by four factors. They are:

- Substitution of capital for energy -
  Capital investment on equipment focusing on energy conservation, such as thicker insulation, large heat exchangers, and other energy-saving devices, reduced inefficient use of energy [294].

- Improvement of existing processes -
  The technical improvements reduce the total costs of an industrial process by 1 to 2% a year on average. An example improvement of existing processes was an extensive use of quality controls which, among other benefits, resulted in saving energy that otherwise would have been used to produce defective products [294]. Efficient light bulbs and other devices can be a significant saver of energy.

- Scientific and technological developments -
  This can enable relatively rapid and profound reductions in industrial energy requirements. In the long run, technological improvements are the most dramatic factor in cutting back industrial energy consumption. Refinements of existing industrial processes would have run into their natural limits long ago were it not for radical innovations. Examples of scientific and technological breakthroughs are the development and use of sensor and computer controls in the process industry [294].
  Scientific and technological breakthroughs in material and product design also play an important role in efficiency use of energy. For example, it is estimated that an improvement of 1% in engine efficiency would save U.S. airlines $100 million in fuel costs each year [11].

- Demand-side management -
  Efficient use of energy can also be accomplished by controlling the users' demand. For example, in the electrical utility industry, the Demand-Side Management has been widely used to improve the efficiency and timing of customer electricity use [153].

- Cogeneration -
  Cogeneration systems make use of otherwise wanted thermal energy, produced by electric or other generation plants. Under the appropriate operating conditions an efficient cogenerating plant can yield 85% efficiency compared with 35% typical for fossil fuel generators.

Environmental Awareness

Rising concern about global warming and acid rain resulting from the burning of fossil fuels is prompting public and government to pay close attention to environmental impacts from energy consumption.

Attention is focused especially on the transportation sector which accounts for 10 million barrels of the U.S.'s daily energy consumption of 17 million barrels of oil. Most of that oil is burned by automobiles [226].

Trade-offs between energy exploration and nature conservation are major items of public debate today.

Government Regulations and Incentives

Government plays an important role in energy conservation. It can control usage of energy directly by putting limits on consumption rate by means of regulations - such as the Congressionally imposed corporate average fuel economy (CAFE) standard for cars; or indirectly by providing incentives to encourage economically efficient energy conservation. The legislation tries to balance energy needs with the environment and the economy to encourage "least-cost" energy options with the lowest total economic, environmental, and societal cost [226].

Alternate Energy

Alternate energy includes a host of "renewable" forms of energy - solar thermal, photovoltaic, wind, biomass and geothermal, for example [226,383].

Renewables now supply 8% to 10% of America's energy, most of it hydroelectric. The Department of Energy estimated that renewables could provide more than 28% of U.S. energy by 2030 if they get more funding and their cost drops relative to oil [383].

International Cooperation

Energy efficiency appears to be in the process of transformation into a significant global force, supported by people and governments in industrialized countries.

Infrastructure

Improvements must rest on a strong educational foundation. Environmental awareness should take root in elementary and junior high schools. Emphasis should also be placed on science teaching which is fundamental to the future supply of scientists and engineers - and to the understanding of their contribution by nonscientists [294].

Plant operators, equipment suppliers, engineering firms and government regulatory bodies as well as financial community must all have long time horizons [294].

Future Research and Development

The research and development effort extends not only to renewables, but also to those based on fossil fuels such as synfuels [226]. The research is not only to increase domestic energy resources to replace oil imports, but also to reduce pollution created by energy consumption [226].

ENTERPRISE INTEGRATION

DESCRIPTION

Integration is the act or the process of cost effectively harmoniously integrating or uniting all parts of the whole to 1) reduce voids and redundancies, 2) cost effectively balance people versus systems versus technology needs, 3) provide understanding of all processes and functions, white collar as well as blue collar, through all phases of product/service life cycle for all organization levels (planning, control, execution).

This leads to the following characteristics for the enterprise integration system, to facilitate flow of information and coordinated decisions and actions.

Enterprise Integration Architecture

Necessary to form a framework to communicate information for all domains (input, output, control) for people/hardware to cost effectively manage a process. One needs to balance the resources and controls (data, software systems and hardware) for all processes. These processes should be logically integrated but physically distributed across heterogeneous systems and hardware, transparent to the user. Data should be entered only once to be used many times. Standards, common business roles and an architecture (covering business and technology systems) are necessary to accomplish integration.

Information Access

It should be easy to access the wealth of information resources and services available through corporate networks. Too often, those that need information do not know where to look or what commands to use. In general, data will have to be integrated from many sources to create customized information presentations for each individual.

Monitoring and Automation

Even if one knows where and how to get information there is simply too much to keep track of. People and software need to be notified of decisions or events that affect them, so that they can take appropriate action.

Cooperative Work

People and computers need to work effectively as teams across time (e.g., through various stages of a product life cycle) and space (e.g., design and production engineers working concurrently to resolve a problem). Team members need to share knowledge and information, and be alerted to potentially conflicting decisions.

System Integration

Independently developed software packages must be easily integrated into the framework so that they interoperate seamlessly and are easily used and maintained.

Additionally, the framework must provide an incremental path for migrating the enterprise from a purely "people-based" operation toward an environment in which people and computers work cooperatively. This evolution must occur without interrupting on-going operations.

Enterprise integration is the industrial analogy of military command and control. It bases the operation of an industry on computerized data; hence it requires the integration of all data in an enterprise on linked computer networks, together with storage of processes to use that data, and of knowledge about the processes and the data, on the network.

Enterprise integration will be as common in 2006 as is the fax machine today. Any company not able to communicate and interact rapidly with other companies will lose its competitive position. The development and coordination needed to establish this is enormous, but the effect will be profound and this effort absolutely necessary.

Enterprise integration includes not only the technical capability of making computer-based data, processes and knowledge available widely, but also the individual skill training and the functional organization needed to generate the computer-based items in a controlled way, and to use them quickly and effectively.

WHY IT IS IMPORTANT

Enterprise integration, like any other process design, should assure that all parts fit, work together, and perform their individual functions to efficiently and reliably accomplish the overall enterprise purpose. White collar service oriented processes are no different than blue collar manufacturing processes, except being more people dependent and requiring even greater need for enterprise integration to manage voids and redundancies.

The benefits of enterprise integration are to optimize the whole, not parts, of the enterprise to be more responsive, achieve higher quality and lower cost and be more flexible to market demand. The result should be able to "do the right things, right the first time, just in time, all the time". Enterprise integration is one key component of a Total Quality Strategy to achieve continuous product/process improvement by cost effectively balancing people, systems and technology needs.

Agile manufacturing requires much reduced product realization cycle times, and reduced reaction time to a customer's order. Many analyses from many industries show conclusively that the time taken to find data, and lack of information at a decision maker when a decision is made, is by far the overwhelmingly important barrier to overcome, to cut down cycle time and response time.

The impact of enterprise integration is seen for instance in the highly competitive and time-critical domain of retailing. Retail outlets, factories and distribution centers are tied together through communication channels linking point-of-sale data directly to factory scheduling and inventory control systems, enabling just in time restocking of fast selling items. A Walmart store in Peoria, for example, running low on particular sizes of a popular dress can be restocked directly from a factory in Spain, with no intermediate warehousing, in about 36 hours, compared to an industry average of six weeks [355].

Ford restructured their North American accounts payable process, reducing staff size from 400 to 100. They did this by eliminating the traditional 3-way reconciliation process (order, receipt and invoice), in favor of a system that paid directly on receipt of authorized goods. A new computer system enabled the receiving department to accept only incoming goods for which a valid purchase order was outstanding. Accounts payable then made payment directly from shipping's receipt advice [355].

Singapore's TradeNet reduced the time for goods to clear the world's busiest port from 4 days to 10 minutes. They did this by creating a trade-facilitation EDI network that linked the information systems of shippers, freight forwarders, banks, and customs officials; statutory regulations were changed to allow electronic clearing [355].

Organizations today are often large and distributed, with different stages of computerization and different kinds of computer software. This uneven development and heterogeneity are major impediments to cycle time reduction across all processes within and between enterprises.

CRITICAL COMPONENTS

Standard Enterprise Integration Architectures

An architecture of networked software is the agreed protocols and other arrangements which enable software processes to communicate, send and receive data, maintain currency, avoid contradictory data, and be understandable to human users. Such agreed architecture does not exist.

Evolving Standards for Product Representations

One needs to be able to represent all the data of a product in a way usable by any process needing that data. This data is not only the geometry, shape, surface finish, electronic, thermal and other technical properties of a product, but also business data such as price, availability and so on.

These standards will never be fixed and static. They will be continuously evolving as new requirements are better understood.

The primary thrust in this area is the PDES-STEP effort. It will be several years until this becomes available and then several years more until systems based on this become available.

A representation includes not only the data defining a product, but also a specification of what process could operate in that data, or possibly the process itself, and also representation of knowledge about the product and production process.

Standardization efforts in the U.S. are fragmented and slow. This is discussed in more detail in the section related to standards. This stands in marked contrast to the efforts in Europe, of many people and organizations, working in a more coordinated way than in the U.S. on standards related to manufacturing.

There are numerous, sometimes overlapping and competing standardization efforts dealing with the exchange of data or the interoperability of distributed systems: PDES, EDIFACT, X12, X.n, OLE, APS, IGES, ODA, SMGL, SNA, NAS, OCE, CGM, EIA, ANSI, CCITT, IEEE, ISO, NIST, OMG, CFI, OSF, Uniforum, Unix International, User Alliance, COS, ISO, IWG, and many more. In addition to these information-industry standards and standard organizations, there are organizations in every major industry developing often idiosyncratic architectures, protocols and data formats for their industries: Sematech, Automobile Industry Action Group, Petrochemical Open Software Corporation, Society of Manufacturing Engineers, CAM-I, EPRI, Aerospace Industries Corporation, and so on. This fragmentation must be rectified.

Heterogeneous Distributed Databases

Heterogeneous distributed database technology based on open systems is a critical component of the enterprise integration systems. This is discussed separately in the section on distributed databases.

Evolving Standard User Interfaces

Currently different computer systems use different user interfaces to interact with them. This creates great difficulties when people are required to change from one using system to another. It is desirable therefore that standard user interfaces be developed for interacting with the data, processes, and the knowledge bases in the enterprise integration information system. This will facilitate people being able to use many different systems within the integrated enterprise. This subject needs much more inter-industry attention and more favorable standard-setting than is the case now.

Unified Training

Enterprise integration requires that people be able to easily work one with another making use of networks extending across the enterprise. In order for this to be achievable, people must understand what the function of the enterprise is, what the functions of the different people in the enterprise are and the functioning of the different systems in the enterprise. It is necessary therefore to generate coordinated training systems for the people in the integrated enterprise. These training systems will require a curriculum of what to teach, to different people in the enterprise, and should generate tools for that education.

Future generations will grow up in a world of computer networks and information, and will instinctively understand what they are, what they do, how to use them, and how to get the most out of them. For the rest of us, training will be needed not only on how to use the computer interface, but also on how to understand a network, what it can do, and how to best use it.

In order that training should be made available to many people in as short a time as possible, it is necessary to develop tools, including video, multimedia, pamphlets and books, and other materials aimed at making the teaching efficient.

The training system will need a system of teaching the teachers, which will be different than teaching the regular work force.

Information Services

In the integrated enterprise, much information will be available to people, but in order to use that information they will need to know where it is, who they can turn to get different things done, and how resources can be used. Information services will be necessary in the integrated enterprise in order that people should quickly find other people and resources they need to do their job.

Computers and Networks

Computers and networks will not be developed specifically for enterprise integration. Enterprise integration will make use of the capability of computers and networks in general.

Encryption, Security, Reliability, Integrity

Use of information in the integrated enterprise will require that information be encrypted for security reasons and that the system will be kept secure from people or processes who should not have access to that. In addition, the system will have to be protected against software damage as from viruses, and from physical damage as from fires. Protection of software from software is a technology still in its infancy, due for a tremendous expansion. Processes, procedures and people will need to be in place to protect the integrity of the data and the backup storage. Alternative routings should be available and automatically used when needed, and the network and data should be protected from failures, for instance, flooding of the network by broadcast erroneous error message. These items are not developed especially for enterprise integration but they will be a critical component.

EVOLVING STANDARDS

DESCRIPTION

The interconnection of communication devices in a distributed network or of mechanical modules in a system is impossible without standards. However, more than one standard are used. As a result, incompatibility of plug in units, communication protocols, storage media or software can lock computer users into choices of equipment, services, and supplies that are a burden in the long run. This situation will not be quickly improved because standards work in the U.S. is too fragmented and slow. In 1989 the Board of Telecommunications and Computer Applications of the U.S. National Research Council workshop on standards stated that the U.S. standard setting process is excessively slow and cumbersome for the era of international competition in high technology industries. In addition, the board suggested that those interested in global trade should contribute to and participate in the standard development process, understand international developments, and support globally accepted directions. Also, they warned that the in-country protectionist standard should be opposed, to facilitate efficient and free market place [391].

Since there are many standards, various committees are trying figure out how to make standards work together, a process they call "harmonization". For example, standards involved in computer readable CAD schematic of a printed wiring board are: EDIF (Electronic Design Interchange Format), IGES (Interim Graphics Exchange Specification), IPC (Interconnecting and Packaging Electronic Circuits), and VHDL (Very High Speed IC Hardware Description Language).

Standards efforts are caught in the constant tension of an unsolvable problem. Freeze a standard now, and better future solutions may be locked out. Wait for the better solution and the continuation of current chaos leads to inefficiency. Strong leadership based on strong technical expertise is needed to steer these decisions.

Developing an international standard is at least a three year process and usually much more. First it is introduced as a draft proposal [74]. The committee reviews the draft and if it passes it becomes a proposal. After circulating to a wider audience, it becomes a draft international standard. The time from draft to adoption of a standard is very high.

WHY IT IS IMPORTANT

Increasingly, industries, service providers, researchers and organizations depend on the availability of data in electronic formats. Data created once in electronic format, is transferred from system to system and used many times. If one sees the comparative life cycle of hardware, software and data in manufacturing, data has the longest life cycle of all three components. When new businesses are formed or older businesses seek new opportunities, standards reduce the risks and expense associated with the development of new information technology-based products and services [237].

In manufacturing organizations, data currently resides in stand-alone systems in many formats. If there are no standard interfaces between these stand-alone systems, the organization will have data handling constraints. For example, a critical element in the design process is to ensure that a common standard for data is used to help with the exchange of electronic product information. Work on product data standards is focusing on defining information standards which can be used by all design and manufacturing engineering areas. These standards must include not only geometry, but material information, functionality and other data.

Standards both expand markets and facilitate competitiveness. International standards are one of the best paths to true global competitiveness.

For concepts like concurrent engineering, simultaneous engineering, reduction of product development time, etc. to be truly effective, common standards for information handling are essential [237]. Overall, industry executives should support the development and application of standards, because they will be a critical factor in reducing the information constraint and staying competitive.

There is a consensus among government and industry committed to CALS and enterprise integration that the unifying technology necessary is PDES. The method that the U.S. has chosen to attain this technology is through an international standard, under the jurisdiction of ISO, called STEP, Standard for the Exchange of Product Model Data. The STEP standard is being developed by 170 experts from 25 countries; 18 of these countries are classified as participating, and 7 as observers. There are 8 organizations participating in a liaison status. Because of disinterest on the U.S. delegations in the past, some decisions were taken unchallenged, by better organized foreign delegations that were not in the best interests of U.S. industry and government. Recently the development community in the U.S. has realized that better representation is required at these international meetings. U.S. representation has greatly improved and some key issues were decided that allow content in STEP that more suits the U.S. needs: e.g., the re-instatement of the electrical models into STEP after they had been removed by foreign delegations a year before.

Many vendors and users are promoting standards for open systems. These standards are intended to allow computers manufactured by different vendors to communicate easily. Software based on standard languages and standard interfaces to operating systems, using standard utilities, should be able to run on different vendors' equipment. Users trained on systems supporting these standards should be able to readily use other systems built on the same conventions.

One of the major areas that lack standards is in user interface to software applications. For example, there is no standard key for functions such as save, exit, help, etc. Standards would considerably reduce the learning curve associated with using various software applications and will provide ease to users. It was estimated that 20% to 50% of software development is devoted to interface development. A survey showed that by reusing 100,000 lines of user interface software out of 500,000 total lines of code, 2,500 staff hours per service application would be saved with a standard Human Network Interface. Overall, by having standards, software development effort, training effort and maintenance effort can be reduced significantly. OSF/Motif is trying to set standards associated with graphic user interfaces [333].

CRITICAL COMPONENTS

Recognition of the Need

The goal of manufacturing systems is to increase competitive strength. One of the factors vital for a successful manufacturing systems is the integration of process, material and information flow, and communication and control systems. Enabling technologies such as Computer-Aided Design (CAD), Computer-Aided Manufacturing (CAM), Computer-Aided Engineering (CAE), Computer-Aided Testing (CAT), Computer-Aided Process Planning (CAPP), Computer-Aided Quality (CAQ), Computer-Integrated Manufacturing (CIM), Computer-Aided Software Engineering (CASE), etc., are modular in nature and share data in an integrated environment. Data can be in different formats, sizes, etc.

It is the goal of this interconnection to direct the right information to the right place at the right time and with complete accuracy. If there are standards, the system will be open, so it can be expanded to both customers and suppliers. The concept of "open" is only achievable by having standards that in turn lead to potential markets. An example of standards affecting an industry is American facsimile. In the beginning, American facsimile companies did not agree on a communication standard. Ten years later, the Japanese conquered the facsimile market.

Standards are required to provide the understanding and representation of products and processes for use by computerized tools, activities and systems. Development and application of standards depends on the ability to define a conceptual schema of product knowledge and data, process knowledge and data, life cycle knowledge and data and enterprise management data.

Standard Setting Organizations

Many organizations are responsible for standard setting, both domestic and international. ISO (International Standards Organization), headquartered in Geneva is the specialized international agency for standardization. National standard organizations of 89 countries form the membership of ISO. ANSI is the U.S. representative, also responsible for setting domestic standards. During December 1983, ISO formed a new technical committee, ISO TC 184, "Industrial Automation Systems". The scope of this organization can be defined as "Standardization in the field of industrial automation systems encompassing the application of multiple technologies, i.e, information systems, machines and equipment, and telecommunications". Two of the standards development efforts under ISO TC 184 which are in particular interest are the STEP (Standard for Transfer and Exchange of Product Model Data) and international standardization of the MAP (Manufacturing Automation Protocol) and TOP (Technical and Office Protocol) [124].

GATT (General Agreement on Tariff and Trade) has exceptional importance and relevance for all companies and organizations conducting business on a multi-national basis. The ISO 9000 standards for quality will become prominent in international trade. Today, with national, regional and international voluntary standard development organizations, participants are aggressively developing standards in the areas such as computer communications, database management, computer graphics, programming languages, and operating systems. These standards promise to reduce cost and increase productivity, while maintaining an open international market for software and services. The multiplicity of groups promising standards is cause for concern.

There are numerous, sometimes overlapping and competing standardization efforts dealing with the exchange of data or the interoperability of distributed systems: PDES, EDIFACT, X12, X.n, OLE, APS, IGES, ODA, SMGL, SNA, NAS, OCE, CGM, EIA, ANSI, CCITT, IEEE, ISO, NIST, OMG, CFI, OSF, Uniforum, Unix International, User Alliance, ISO, IWG, and many more. In addition to these information-industry standards and standard organizations, there are organizations in every major industry developing often idiosyncratic architectures, protocols and data formats for their industries: Sematech, Automobile Industry Action Group, Petrochemical Open Software Corporation, Society of Manufacturing Engineers, CAM-I, EPRI, Aerospace Industries Corporation, and so on.

ESPRIT (European Strategic Program for Research and Development in Information Technology) is a multi-year R&D effort through the commission of European Communities, for the enhancement of European Communities in Information Technology. The 1984 plan gave a projection for an estimated 7199 man-years of project effort in five key areas of enabling technology, to be expended over 5 years [124]. This is a considerable effort, in the following areas:

- Advanced Microelectronics - 1,670 man years
- Software Technology - 1,440
- Advanced Information Processing 1,695
- Office Systems - 1,450
- Computer-Integrated Manufacturing (CIM) - 944

The CIM category consisted of two sub-categories: Communications Networks for Manufacturing Applications (CNMA); and Open Systems Architecture (OSA). Due to the large number of projects in CIM, the six work plan areas under CIM are:

1 Integrated Systems Architecture
2 CAD/CAE
3 Computer-Aided Manufacturing
4 Flexible Manufacturing Systems
5 Subsystems and Components
6 CIM System Applications

Testing and Diffusion Capabilities

The objectives of testing are:

- To validate standards against user requirements;
- To evaluate the effectiveness of standards which includes identification of need for improvements and prototyping conformance/acceptance tests; and
- Evaluate new technology - identify requirements for new standards and identify usefulness of technologies.

Testing of standards include activities such as defining goals and scope, project planning, administrative tasks and technical tasks. In the process of international standards testing many organizations need to cooperate. Studies show that 20% of total annual development expenditure is for the validation of standards. Before publishing the standard, the testing and validation process should both be economically feasible. Today evolving standards should aim toward a single set of internationally acceptable tests.

FACTORY AMERICA NET

DESCRIPTION

Two of the unique strengths of the United States are its leadership position in information science and technology and its massive diversified supplier base. Combining these two strengths provides an extremely powerful and unique asset.

Factory America Net is a value-added network that will tie together a large percentage of American manufacturers and suppliers into a cohesive on-line community.

Factory America Net will service the manufacturing enterprise community, much as the Internet, which developed from the Arpanet, ties together universities and research organizations in 47 countries. In approximately twenty years the Internet community has grown to the point where 444,000 nodes in the United States and another 125,000 nodes in the international community service millions of individuals in thousands of organizations. Arpanet became functional twenty years ago through the active development and introduction of DoD's DARPA arm. Virtually any university or research organization can now become a member of the Internet community by setting up the appropriate network node configuration consisting of a computer capability and specialized software. The node is connected to other nodes throughout the entire Internet system and provides access for a community of users over all organizations in the network. These users then have access to the entire Internet community and services provided specifically to facilitate the interchange of research information and promote interactive research activities.

Factory America Net is envisioned as a utility that will enable inter-enterprise integration and the virtual corporation. Just as enterprise integration within a given organization will streamline its abilities for concurrent activities and information exchange, inter-enterprise integration will tie a corporation into its entire supply base and its customers. Where the Factory America Net is employed to forge a joint venture among a number of corporations, it will tie together those relevant pieces in each company in pursuit of a specific market opportunity; we then have what we call the "Virtual Corporation". The concept of the virtual corporation is described elsewhere.

Principal early uses and motivators for the development of the Factory America Network are the currently active pursuits of electronic data interchange and concurrent engineering among companies and their suppliers. Both EDI and concurrent engineering activities currently being explored place an extremely large burden on the small supplier involved because the technology is not yet mature, and standards are lacking. A key function of the Factory America Network will be the adoption of defacto standards for all forms of electronic commerce and engineering between companies using the network.

Aside from basic network services, Factory America Net will accommodate third party services and data bases appropriate for the manufacturing enterprise community. Thus, we would expect to find brokering services that help match companies with resources of all kinds including the identification of potential partners for specific opportunities and requirements. Requests for quotations and calls for participation and other such opportunity notices that are published today in a variety of places would be on-line and available to everyone on the network. The supply base nationwide would have full and complete access to all of the opportunities nationwide as they become available. The major manufacturers in need of capabilities and resources would have instant access to the entire nation's supply base.

WHY IT IS IMPORTANT

The act of concurrent engineering requires that process design activities occur simultaneously with product design activities. In most cases, machines and systems are designed by firms that specialize in these areas and must work concurrently with firms whose function is to produce products. These activities require a vast amount of information interchange on a constant basis, much of it in the form of engineering drawings. Factory America Net will provide suitable data interchange services and standards so that a relationship between a supplier and a manufacturer is easy to establish and easy to maintain regardless of previous activity histories and distance between locations.

Factory America Net is also the marketplace for finding a manufacturing facility that can make a small run of required spare parts, a special one-off quick-response part, a source of inventoried materials, a place that can accommodate an immediate tooling requirement, or even a group experienced in certain technologies.

In the age of rapid realization an organization will often be faced with a requirement or an opportunity that must be executed swiftly beyond its internal capabilities. It can easily access The Factory America Net and find the required capabilities, partners, and subcontractors, with a team validated and in place. Factory America Network facilitates the interchange of active project activities and information throughout the entire course of the project. Used in this fashion the participants form a virtual corporation with a period of time that they are engaged jointly in the required activities. This virtual corporation may be composed of units involved in some research, units involved in technology developments, units involved in manufacturing subsystems, units involved in assembly operations, units involved in distribution, units involved in servicing, and units involved in financial accounting and administration of the virtual corporation.

CRITICAL COMPONENTS

In order to tie the diversified supply base of the United States together in the Factory America Network it will be important that the acquisition entry level costs for obtaining a node and training people to use the network capabilities is affordable by small enterprise. Nodes may come in various sizes to accommodate the needs of larger organizations differently than those of smaller organizations. First and foremost, however, the requirement to satisfy the small supplier is crucial to the activities of the major manufacturing enterprises. If the target for nominal network membership is to include the companies whose revenues are $3 million per year, it will be necessary to have total acquisition and training costs well under $50,000.

Migration methodologies will also need to be available to help the small firm make use of its network access without revamping its internal operations. These methodologies need to recognize that, with time, a company can become more and more involved in the network community and make more investment as it receives incremental payoffs along the way. Thus, it will be important to identify certain basic capabilities that can easily be accommodated in a large majority of the supply base without requiring major or even moderate changes in their internal operations.

Interchange standards for the network must be established to accommodate various kinds of information that must flow. Regardless of the standards that are established for network traffic, translators and filters that can take the information representations common and typical amongst the small supplier base community and transform them to and from the standards for the network will be needed.

On-line concurrent engineering technologies must also be developed. The Factory America Network should accommodate much more than the simple interchange of drawings and information it should facilitate the interactive participation of teams involved in the act of concurrent engineering.

Just as we need to develop methods and technologies that support concurrent engineering in an on-line environment, so must we deal with the on-line concurrent enterprise. Concurrent engineering is today's focus. Tomorrow's focus will be concurrency on a much broader scale across all of the activities involved in the manufacturing enterprise. Methods and technologies that facilitate the interaction of diversified groups and teams involved in the many different aspects of business must be addressed.

Groupware is a technology in a very early stage of development currently that must be extended into the realm of the Factory America Network. This groupware must deal with concurrent team activities and widely disbursed locations interacting in real time and perhaps including people of different nationalities and language capabilities.

GLOBAL BROADBAND NETWORKS

DESCRIPTION

By 2006, the economic health of a country will be strongly determined by the size and effectiveness of its broadband communications network. The elements that are necessary to construct a future broadband network are already becoming available. The fundamental element is high capacity (bandwidth) fiber optic cable for use in both the trunk network and subscriber loops. In most instances these elements are being introduced for reasons other than to provide broadband services. To some extent, therefore, the implementation of an integrated broadband network is inevitable. Consequently it is instructive to investigate the applications to be supported and services to be provided by such a network.

Broadband is defined as the provision of subscriber access at bit rates in excess of 2 Mbit/s (or 1.5 Mbit/s in the United States)[130]. For comparison, the telephone network uses rates of 0.0001 to 0.3 Mbit/s, and television operates in the range 3 Mbit/s to 3000 Mbit/s. Broadband operates up to approximately 3000 Mbit/s. In 1990, the fastest working link of its kind anywhere in the world is a 100-kilometer link transmitting at 20,000 Mbit/s [326].

Broadband services are the facilities (switched or non switched) that a network operator provides to support broadband applications via an integrated subscriber access; that is, a single network port which provides access to all services. Although some broadband services are today provided by independent networks (e.g. videoconferencing networks), integrated access will be an essential feature of the future broadband network.

Broadband applications are any end uses of the broadband network capabilities. Typical applications include LAN (local area network) interconnection, videotelephoning, and videoconferencing. In particular, a network capability may be used by many applications.

WHY IT IS IMPORTANT

Broadband networking on fiber optics is inexorably becoming the networking method of the future. The question for manufacturing industry is not whether to take advantage of that move, but who will be ahead of the others, and how broadband will be incorporated into manufacturing.

In the future fiber optic broadband networks will lead to better network conditions at a lower cost [372]. Currently, the cost of fiber maintenance is between 10% and 20% higher than copper wire and is expected to fall 10% a year as fiber is deployed. Full benefit of fiber will not be completely measurable until total copper wire has been replaced -- maybe in 20 years. Fiber optic cables are more reliable and have a longer and useful life [247]. The trend is that underground copper cables are becoming more a liability than an asset. Copper and associated labor costs, continue to rise.

CRITICAL COMPONENTS

Widely Developed Infrastructure

The telephone system, to be effective, must connect all the telephones with whom one wants to talk. Similarly, broadband communications, to be effective, will need to connect to every location requiring that service. Regular commercial and regulatory practice will dictate the pace and distribution of infrastructure installation. Because of the importance of broadband communications for manufacturing, the point of view and requirements of manufacturing should influence the development of the infrastructure.

The FCC (Federal Communications Commission) compiled vital statistics on fiber optic cable deployment in the U.S. [187]. The telecommunications networks of the United States have three major pathway elements.

- Subscriber loop between a customer's home or office and the serving local central office;
- Interexchange trunking within a Local Access and Transport Area (LATA) that interconnects various local central offices; and,
- Intertoll trunking network between Points of Presence (POP's) of a given LATA to a POP in a different LATA.

The three major intertoll carriers (AT&T, MCI, Sprint) have deployed 86% of the total intertoll carrier fiber network, an investment of $5.7 billion. This investment has connected most local networks to each other. This is a considerable achievement, but leaves two requirements to complete the data network.

- The switches on the fiber network are of a speed suited to telephone and need to be replaced by fast switches for data.
- The local network needs to be linked to the factory, office, or home. The total investment for this is $200 billion, and cannot be accomplished in less than 15 years. However, priorities in the completion of the network could be specified. Note the analogy with the Rural Electrification Act. Market forces will gravitate to placing the subscriber connections in populated wealthier regions, locking out other regions from the era of agile manufacturing, and exacerbating economic problems.

The fiber boom is taking place all over the world. World demand rose from 1.5 million kilometers in 1985 to 5 million in 1990, of which 50% was accounted for N. America [15]. By the end of this decade, 10 countries in The Asia-Pacific region will be using at least 1.3 billion fiber-optic circuits [88]. Japan is well ahead in the fiber game. In 1990-91 many ambitious projects such as U.S./Japan link, Hong Kong/Japan/South Korea link, U.S./Canada/Japan link, etc., are taking shape [14]. In the period 1982-1996 investment in undersea fiber cabling by region is 51.33% for the pacific, 37.23% for the Atlantic, 5.68% for Mediterranean, 4.97% for the Caribbean and 0.49% for Persian Gulf.

Developed Broadband Service Capability

Use of the infrastructure depends upon having service and advice available to make it useful for a particular application, until at a time some years hence it will become a mature and stable, fully developed, technology.

The shape of the future broadband Integrated Services Digital Network (ISDN) will be determined largely by the services and applications that it provides. There is an almost unlimited range of possibilities, and the final choice will depend on the users. Existing demand for services such as high speed interconnection between local area networks is pointing the way to the most viable services during the initial introduction phases.

Neglect of the important developing infrastructure by the manufacturing community can lead to investments which do not deal sufficiently and suitably with needs for manufacturing. Other applications will then take relative priority.

Standards

In order to be effective, a broadband network has of course to be built around standards.

Standards are dealt with in "levels". The "lower" levels deal with questions of getting the digital information from one node to another reliably, quickly, and as error-free as possible. Above that are levels which deal with reliable optimum transmission of whole "messages", packets, files or other chunks of messages.

Above that are standards which deal with applications using the network, such as electronic mail, file, transfer, video picture transmission and so on. The quantity of standards and the technical questions dealt with are many and myriad, and will go forward whether or not the manufacturing sector is specially represented. It should however be realized that standards will be constantly evolving over many years, until broadband becomes mature. There is criticism that standards efforts are both fragmented and slow (see section on standards).

Software and Computers

Fast computing and large-scale software systems are fundamental to broadband communications. Development of these capabilities will be critical to technology in general, and will contribute also to broadband communication.

User Terminal Devices

Advances in user terminal devices will facilitate access to broadband communications in general. Development of these devices will be part of the broadband effort in general. Needs for manufacturing environments should be brought to influence directions of development. In particular, the user interface should be standard across each industry sector and as far as possible, across all industry.

Consider the example of word processors. There are many word processor packages, each with a different user interface. The time and trouble involved in learning a new word processor inhibits even computer-literate people from learning a new and different package. Similarly, people have difficulty operating as simple a machine as a VCR, and even some oddly-designed television sets cause difficulty. Broadband enables many different voice, touch, and visual devices to interact with it. Lack of one unique standard leads to different dissimilar terminal devices. This will severely slow down the penetration of broadband techniques to manufacturing. Currently, no organization is dealing with this question from a national manufacturing perspective. As broadband communication expands, much inefficiency will ensue from lack of standards for user terminal devices. There is need for an organization which can engender wide acceptance for a standard to step forward.

GLOBAL DYNAMIC MULTI-VENTURING

DESCRIPTION

Global multi-venturing refers to business alliances aimed at creating competitive collaboration to strengthen companies' competitiveness in foreign markets. Currently, most collaboration is focused on strategic alliances in the form of joint ventures, outsourcing agreements, product licensing, cooperative research, etc. The participants normally are competitors who share common products and/or markets. Examples are collaboration in the automobile industry between Chrysler and Mitsubishi, or in the semiconductor industry between IBM and Siemens.

As the world market expands, companies will be more responsive to opportunities in overseas markets. No company has within itself all the resources available to take advantage of the opportunities at short notice. Therefore, it will be necessary to form alliances not only at the strategic level but also at the tactical and operational levels which will be more focused on capacity and resource sharing. There will also be many more new forms of collaboration to facilitate rapid cooperation between dynamic multi-venturing companies.

Global multi-venturing becomes a lower cost route for new competitors to gain technology and market access. It reduces capital investment and associated risks. For example, Motorola and Toshiba have entered into a collaboration agreement. The agreement calls for Motorola to release its microprocessor technology incrementally as Toshiba delivers on its promise to increase Motorola's penetration in the Japanese semiconductor market. The greater Motorola's market share, the greater Toshiba's access to Motorola's technology [143].

Global multi-venturing also allows companies to leverage their investment. For example, NEC is the only company in the world with a leading position in all the fields of telecommunications, computers, and semiconductors while investing less in R&D (as a percentage of revenues) than competitors like Texas Instruments, Northern Telecom, and L.M. Ericsson. Its string of partnerships, most notably with Honeywell, allowed NEC to leverage its in-house R&D over the last two decades [143].

Companies can increase production capacity through global multi-venturing, mostly in the form of outsourcing arrangements. General Motors buys cars and components from Korea's Daewoo. Siemens buys computers from Fujitsu. Apple buys laser printer engines from Canon [143].

WHY IT IS IMPORTANT

It is today so obvious as to be almost unnecessary to state explicitly, that the world is a global market in a global economy. To survive in that world, dynamic multi-venturing and cooperation will be not only across the nation, but worldwide.

CRITICAL COMPONENTS

Protection of Intellectual Properties and Proprietary Skills

Global multi-venturing offers opportunities for companies to enhance their internal skills and technologies by learning from their partners. However, partners in a competitive collaboration can also become competitors. Collaboration can increase the chances of success in future head-to-head battles.

In the short run, the quality and performance of a company's products determine its competitiveness. Over the longer term, however, what counts is the ability to build and enhance core competencies - distinctive skills that spawn new generations of products. Therefore, companies must guard against transferring competitive advantages to potential competitors. Failing to do so may result in being displaced from value-added activities or being driven out of the market [143].

Rapid Cross-Culture Cooperation Mechanisms

In the rapid changing world, time is a critical factor for success. Companies have to be more responsive to opportunities which may require resources which no one company will have entirely within itself. It is important to have a mechanism that allows rapid cooperation between companies while overcoming the cultural and language barriers. Such mechanisms will require cooperation between governments and legal communities.

In today's corporate legal environment, a wide variety of routine legal actions can be rapidly taken by following prepared models for accepted practice; for instance, standard procedures for registering a corporation, sale of property, etc. There should be similar "instant formulas" which can be easily tailored to meet the specific needs of a global multi-venturing company.

Cooperation mechanisms should also address the issues of national securities and competitiveness. The objective of the mechanism should be not only to run the business smoothly, but also to ensure that a company emerges from an alliance more competitive than when it entered [143].

For more details on cooperation, see "Cooperation Elements".

Education and Training

Managing of cross-culture cooperations in global multi-venturing will require human resources with different skills [112]. The focus will be on managing diversity which requires awareness and understanding of different cultures, languages, and legal systems. Such skills cannot be easily taught in a short period of time. Therefore, they should be included in the national and industrial education systems.

Flexible Enterprise

Global multi-venturing will require companies to be more responsive to a continuous change environment. It will demand an unprecedented flexibility in designs, product/process technologies, and applications technologies [112]. There will be more emphasis in reconfigurations of hardware, software, and processes.

A good example is a label printing process using ink-jet printing at the Campbell Soup Company. This technology has allowed labels that are customized on a short-run basis to be produced for food products tuned to regional taste requirements. Ink-jet printing avoids the necessity of and time involved in changing printing plates, which had traditionally been the barrier to short-run labeling. Ink-jet printing allows the company to not only produce its twenty varieties of a soup - flavored to regional taste - but to label them differently, stressing different points of regional marketing appeal [112].

See "Agile Enterprise Flexibility Elements" for more details.

GROUPWARE

DESCRIPTION

Groupware systems are computer-based systems which support two or more users working in a tightly coupled fashion on a common task. They pertain to the class of systems that encourage organizational collaboration and coordination. An example of this kind of systems are outline editors specifically designed for use by a group of people working simultaneously on the same idea [107]. Computer supported cooperative work deals with the study and development of systems that encourage organizational collaboration. Today's groupware products fall under that category. Projects can be classified into three categories [110].

1. Tools for augmentative collaboration and problem solving within a group geographically co-located in real time.
2. Real-time tools for collaboration among people who are geographically distributed.
3. Tools for a synchronous collaboration among teams distributed geographically.

This technology is still in the embryonic stage. Simple capabilities exist on several well-known operating systems, such as the talk, chat and write facilities which permit simple interaction on UNIX, VM and VMS systems. Capabilities as discussed above are under development among a few specialist groups.

Many computer technologies paved the way for groupware concepts. Today's database technology allows multi-user access to data but does not distinguish users beyond the security check or password access [385]. Groupware applications might monitor changes in such a database and alert different people to specific changes relevant to their job.

Artificial Intelligence techniques can be used in groupware software design [80]. Intelligent groupware can provide intelligence in functionality and user interfaces.

WHY IT IS IMPORTANT

In the next stage of manufacturing, people working in groups with a common task will be a day-to-day practice. Organizations will be integrated into large complex systems. Dynamic networked enterprises will be formed for specific business opportunities. The existence of groupware products will be necessary in this environment in which coordination and encouragement of collaboration are essential for success [328]. Multi-party interactions are becoming an increasingly important abstraction for the design of systems that are distributed, flexible, integrated, and automated.

CRITICAL COMPONENTS

Coordination Theory, Technology, and Software Tools

Coordination theory deals with the problem of implementing a synchronous activity between two or more processes in a distributed environment. An important enabling element in groupware systems is concurrency control methodology, in addition to the technology required for multi-user systems. Currently, there are already several commercially available PC-based groupware software for applications in the areas of workgroup communication (computer conferencing), document editing, and team development [254].

Coordinated Set of User-Interface Principles

There should be a common set of principles over the many application areas [110]. Groupware systems that are currently under development are time consuming to build and to maintain, and difficult to introduce into organizations. As an example, within the Apple Macintosh or DOS windows environment, users of different applications have a common method of interacting with each application; similarly, a coordinated set of user-interface principles will facilitate the implementation of groupware applications.

Successful Systems Should Have

- A coordinated set of user-interface principles over many application areas.
- Grades for user proficiency - user with little knowledge of the system will be able to access and use easily since they are part of the community.
- Ease of communication among, and addition of, work domains. It should be easy to move and communicate between domains and possible to install new tools.
- User programming capability - users must be able easily to interface new tools and extend the language to meet these needs.
- People support services should offer many services such as database design and administration training, cataloging and retrieval of information.
- Recognition of standards for information exchange and ranges of hardware.
- Careful development of methodologies - people-supported services need careful attention in developing procedures and methodologies.
- Co-evolution of roles and organizational structures and technologies.

HUMAN - TECHNOLOGY INTERFACE

DESCRIPTION

Standard accepted interfaces for people to interact with technology systems are necessary. Currently, interfaces are not standard and this leads to great inefficiencies in the work environment.

This can be illustrated by several examples. Consider automatic gears in automobiles. In every make and model of car these are arranged in the same order from P for park all the way through 1. A driver in any car with automatic transmission can in a very short time understand how to operate the gear lever and can drive off. Now consider another example. Word processors in computers have different user interfaces. As a result when a person gets used to one word processor he or she is very reluctant to move to another even if the other word processor provides better functionality, because of the difficulty of learning the new user interface. Or, a third example. Voice mail systems use the # key as part of the control to give instructions to the voice mail system to read messages and so on. In many pay telephones the # key is used by the credit card system in order to indicate that another call is to be made on the same credit card. It therefore is not possible to read one's voice mail from such a coin telephone. If standard interfaces had been defined for these systems such problems would have been avoided.

WHY IT IS IMPORTANT

Employees in the manufacturing enterprise will more and more be interacting with technology systems in order to do their work, in particular with computer-based systems. Everyone throughout the whole system from the back office through design, sales and marketing to manufacturing will be using such systems. As the matter currently stands the interface to each system will be different for different systems. This leads to tremendous inefficiencies and loss of time for training when employees move from using one system to another, and is a serious inhibitor to the introduction of new and better systems in some organizations. Furthermore, there are serious safety implications for the interfaces to the computer and technology systems in the production process.

The entire manufacturing infrastructure would be much more efficient if standard interfaces were available to all the technology systems which people in the entire organization had to use.

CRITICAL FACTORS

Adoption of Standards Based on Ergonomics

There is insufficient standardization in this field with a result that there are many different user interfaces. This places a tremendous burden on each individual worker, a tremendous burden on the education and training system and leads to great inefficiency in the manufacturing production process.

In the initial stages of development it is counterproductive to force standardization because the older methodologies are standardized and the newer techniques are not incorporated. On the other hand, although technology improves all the time there comes a stage when standardization must be mandated and forced. There are current input/output devices which have been used for a number of years for which all the technology exists to standardize. For instance; the keyboard, the computer screen, and various other systems which have been in use for a number of years, are in need of standardization.

Statement of Need by Large Customers or Groups

Manufacturers of the technology systems usually do not see an advantage to themselves in providing standardized interfaces. Very often they provide their proprietary interfaces in the belief that they do indeed have a better interface than the competition. Although it may be true that the interface for a particular system is better than for competitors' systems, the fact of having many different interfaces may be inhibiting the growth of the market in general. It is not clear that using different proprietary interfaces is indeed conducive to market share and the long term health of each manufacturer. However, there will not be standardization of user interfaces until large organizations such as the DoD, the automobile industry or other large groupings of industries insist on such standards.

Development of New Technology

As time goes by new technologies will be developed, such as very capable speech understanding systems, 3-D terminals, handheld devices for virtual reality, collaborative work environments, user interface development systems and so on. As matters stand currently each developer of such new technologies will develop his own interface. There should be a clear delineation in the development of new technologies whether the technology is at a stage before the standard human interface has been decided and standardized or whether after that time. Lack of standardization leads to discoordination between various systems and leads to inefficiencies which new technology however good will not overcome.

INTEGRATION METHODOLOGY

DESCRIPTION

As production systems become larger and larger with tighter coupling between the different components, it is becoming apparent that a methodology is needed to deal with the system as a whole. Current practice is to regard each item independently and to tie them together with inadequate approaches for dealing with the system as a whole. As a result, the design implementation and integration have large software control systems which becomes highly unpredictable in resource consumption and in time response. Once these systems are built and accepted, they are rarely changed because seemingly simple improvements can cause unpredictable side effects and loss of production. Furthermore, the systems are constructed such that it is extremely difficult to incorporate updated technologies and improvements. Current design and approaches for the construction of such large systems deal with integration as a one-time affair rather than a continuous ongoing process. Methods are needed for which parts of the total system will function independently and can be changed and updated independently without affecting the operation of other parts of the system. This requires a systems design such that each of the components can be upgraded and the whole system controlled by a method independent of the properties of each component. Each module needs to be protected from the effects of each other module and yet the system as a whole has to be coordinated. Such methodologies are called autonomous module methodologies, or holonics methodologies, or subsumption architectures, or agents and actors, and are being investigated today by a number of researchers [51,257,258,127].

Standardization is needed in order to enable messaging among autonomous modules created by different designers. This needs a definition of an "open" standard and possibly the development of a neutral generally accepted manufacturing language. Such an architectural language would take into account generic unit operations of production and a range of generic responses that the units would have for acknowledgement, request and so on. This standardization would standardize interaction and coordination dialogue between independent units in the system, both computer modules and human operators. Such standardization would be necessary in order to attain widespread use of these newer and highly promising technologies in manufacturing.

The subject is still in the research stage with approaches being made to beta-site testing in industrial settings. There is still a considerable amount of work needed in order to define the best systems and to have them implemented adequately.

WHY IT IS IMPORTANT

Current design of manufacturing production processes concentrates on the design of each component of the process, each machine or software module. These are integrated into a whole without standard methodologies for the design of the interaction of the whole system being in place. This approach is reaching the limits of its capabilities and is leading to systems with unpredictable side effects and which cannot be upgraded piece by piece.

INTELLIGENT CONTROL

DESCRIPTION

An intelligent control system has the ability to make decisions in real time based on process and environment models and sensor data. Artificial intelligence techniques, embedded in the intelligent controller, enable it to reason about dynamic environments, make adaptive corrections and predict future behavior of the system. Communication among intelligent controllers will enable the change of downstream parameters to improve product quality and reduce down time in production lines. Current trends and methodologies of intelligent controllers are given below.

In 1987, a number of observers predicted that U.S. manufacturers will increasingly switch from AC power to DC power for control system application. Controllers and sensors will then be faster since there is no limit in frequency compared to AC power which has only 60 cycles per second frequency. Europeans already use DC controllers that are faster, smaller and less expensive [188].

Many experts predict that the role of electronics and control systems will increase in almost all industrial sectors. For example, by the end of this decade the average automobile will contain electronic-sensor-controller components costing $2,000 [2].

Major changes are taking place in the controller industry. In the temperature control sector, prices are decreasing, and new control strategies are being implemented to solve tuning response time problems. Experts predict that to make controllers any smaller at this point would increase their price and decrease the features [63]. In addition, there is a trend to developing more and more sophisticated algorithms for better performance - at least in auto-tuning and adaptive control.

Fuzzy logic is becoming a part in intelligent control system design. Today the trend is to develop fuzzy logic processors [384]. Companies have already started to market fuzzy processors with resident knowledge base memory (KBM). The KBM can be EPROM, RAM or ROM with maximum size of 64,000 16-bit words and input and output with 8-bit precision words. The KBM can handle up to 800 rules and can perform up to 100,000 rule evaluations/sec. Also, fuzzy logic technology can be significant for control systems. For example, a recently developed fuzzy logic controller was able to produce a mold in 35 minutes instead of 51 minutes [174].

An area of significant potential to intelligent controllers is artificial neural networks [379]. Such networks have been applied to the problem of learning about unknown system parameters. Intel has produced a neural net chip which is reported to be more effective throughput for neural net calculations than a Cray computer [380].

An intelligent controller has been applied in an automated assembly [324]. The objective is to provide an intelligent environment for a robust rapid product development. The system consists of two hierarchic levels. The higher level deals with supervision of assembly execution and error recovery. The lower level deals with machine control and compensation for environmental uncertainties.

Today's programmable controllers can accept up to 12,000 inputs and outputs and work on the widely acceptable VMEbus standard so that multi-vendor equipment can be attached to them, using open architecture [174]. Additional features such as parallel processing are becoming common in these programmable controllers.

One of the limitations of current control system technology is the lack of a universal standard. However, the market trend is towards open standards but the customers are still looking for quality products with proprietary standards provided by mature vendors [140].

WHY IT IS IMPORTANT

Control systems play a vital role in enhancing product quality and flexibility of automatic production lines. Intelligent controllers provide new capabilities beyond those of conventional controls. The ability to handle uncertain systems, which may involve fuzzy representation, combined with adaptive performance and decision making capability, make these controllers more effective in controlling production systems.

Current diagnostic systems can identify a malfunction and its location. The intelligent controller, however, enables prediction of a fault condition. Therefore, the availability of intelligent controllers will increase up-time (mean time between failures) and reduce down time (mean time to repair). Altogether, the reliability of an automated system can be improved using intelligent controllers. By using intelligent sensors connected to intelligent controllers and computer-controlled data collection and analysis systems, plant diagnostics and predictive maintenance strategy can be achieved [2]. In manufacturing systems, failures or breakdowns are very cost consuming. For example, a breakdown in a coal-fired electric generation plant will cost about $500,000 in energy replacement per day [2].

Lot sizes are getting smaller and customers are looking for more variation in sizes, shapes, colors and features for the products. This leads to more flexible systems. These flexible systems will be equipped with multi-tasking machines, automated material handling systems and supervisory control system. These multi-tasking machines are operated with intelligent control technology [339]. Also, machines or systems equipped with intelligent control technology will be easier to use, maintain and operate.

Intelligent controllers can support management functions such as on-line real-time status of parts, analysis of the production process, etc. The real-time data is vital for operational decision making.

Intelligent controllers can enhance productivity without adding more supervisory staff to the factory floor by monitoring the production system and pin-pointing the causes of down time, and automatically rerouting the production. In one case a spokesman for a manufacturer stated that the overall production level was improved by at least 15% by having intelligent controllers [12].

CRITICAL COMPONENTS

Hardware

The intelligent controller consists of a computer, sensors and many components such as programmable controllers, servoamplifiers, sensors, actuators, etc. The capability of controllers may be classified in terms of number of inputs and outputs. Downward migration of computer technology added sophisticated functions to the control system such as distributed control so that a computer can control both local and remote controllers. On the hardware side, experts predict that "users should plan for today's large system to function as a part of the much larger system that is likely to exist in the year 2000" [98].

Communications

Communication links allow intelligent devices to exchange data. The system allows coordination of efforts between devices, leading to faster and better problem solving and early detection of potential problems. The technical limitations of standard serial ports paved the way for many proprietary communication links. In controllers, the communication link is critical for achieving real-time control. Manufacturing Automation Protocol (MAP) is a recognized standard approach.

Software

Development of intelligent controls requires integration of control theory and artificial intelligence. Methods that are frequently utilized in intelligent control includes pattern classification, search techniques, adaptive control, predictive control, fuzzy logic, neural networks, and learning techniques enabling the controller to improve its performance over time. Expert system shells are widely used in controller technology especially in localized decision making, diagnostics, etc. Today's intelligent control system software provides an easy graphical user interface to the operator and helps to pin-point problems fast by providing detailed recommendations for corrective action.

INTELLIGENT SENSORS

DESCRIPTION

In today's integrated systems environments, intelligent sensors are a vital part of instrumentation and control technologies. The emergence of manufacturing automation techniques has increased the demand for cost-effective sensors which monitor processes. An intelligent sensor is defined as one or more transducers plus the circuitry to provide at least the first level of signal processing, and capability to respond in a variety of different ways to commands received from a host computer. These responses might include initiating self-test routines or adjusting compensation coefficients [388], and even converting a physical change into a decision controlling a process [228]. The main functions of these sensors include:

- Sensing changes in environmental conditions such as dimension, pressure, temperature, cracking, failure, color, smell, etc. and compensate for these changes.
- Interfacing with other systems such as actuators or controllers in an understandable and acceptable format through two-way communications.
- Ability to detect or diagnose its own operating problem or failure and report the details to the system.
- Ability to make decisions and/or actuate control elements by having embedded logic.

Intelligent sensors are an integral part of developing intelligent machines or processes and are critical to validate the performance of the machine or process.

By using an intelligent sensor directly connected to the actuator, some of the controller's burden of making the process changes can be off loaded to the smart sensors,

improving system efficiency. In addition, a intelligent sensor can track and analyze raw data before sending to the controller. For example, in statistical process control (SPC), the intelligent sensor can find the number of inspections, calculate maximum, minimum, average, mean, etc. This will allow the controller to access data as and when required to meet customer specifications.

A study in 1986 showed that the world market for industrial sensors and transducers will grow at the rate of 6.9% per year [314]. The market for solid-state sensors grows at the rate of 15% per year. The market for fiber optic sensing is expected to grow to $380M by 1994 [149]. Fiber optic sensing is immune to electro-magnetic interference, which is important in many circumstances.

Solid-state sensors can be produced with high yield and can be merged with integrated electronics. For some type of solid-state sensors, accuracy is approaching 16 bits, and VLSI interface circuits are being defined to allow features such as self-testing and digital compensation to be used [387].

Smart sensors are now becoming extremely popular in instrumentation and control applications. Another popular technology is sensors equipped with transmitters. However, this method is not popular as yet due to high cost of using the technology. The advantages of this radio frequency sensor is that it can be placed in difficult to reach places, or inside rotating spindles or tools (e.g., a force sensor in a milling cutter). Another trend in sensor technology is that the size of the sensors is becoming smaller, and they are built using solid-state techniques.

Fusion of information from multiple sensors, by computing the implications of the data taken together, is becoming important. This can use the techniques of artificial intelligence or neural networks. This capability will increasingly be found on electronic "chips" together with the sensor [314].

Intelligent sensors that are available for industrial interfacing/integration can be classified as follows [228]:

Presence/absence

Optical inspection sensors that include a camera are used in a great deal for presence/absence detection. The categories that are available include object recognition sensors, linear array sensors and color sensors.

Positioning

These sensors are used to detect the position of an object include a combination of limit switches, photoelectric and proximity technologies. Today, opto-electronic technology is able to provide sensors that detect the position of edges and widths, thus achieving distance and thickness sensing.

Distance and Thickness

Infrared and laser beams along with triangulation techniques or ultrasonic sensors are used for this application. Another example is a linear array sensor with structured light source.

Pressure Sensors

Piezoresistive pressure solid-state sensors and capacitive pressure solid-state sensors, that can be computer calibrated, are available [388].

Identification

Optical sensors are widely used in identification. The object-recognition sensors look for a particular feature or mark on the object. Bar codes and laser scanners are widely used in identification.

Inspection

Inspection sensors play crucial role in quality control techniques. They can perform part dimension measurements and surface finish inspection. Many techniques such as vision, linear arrays and lasers can be used for this sensing.

WHY IT IS IMPORTANT

The ability to monitor products and production process equipment, to feed the data to a computer network and to take action rapidly based on that data is fundamental to agile manufacturing.

CRITICAL COMPONENTS

Tangible vs. Intangible Variables

Examples of tangible variables are temperature, pressure, weight, etc. These variables are not only used in controlling the process itself, but also to record the history of the processes [228]. The sensors used for measuring tangible variables include electro-mechanical limit switches, photo-electric controls, ultrasonic sensors, optical sensors, proximity sensors, etc. The intangibles include variables such as taste, smell, color, texture, composition, etc., where there are no specific unit of measurement to measure the variable [103]. The direct measurement of these intangible variables is difficult. Low cost microprocessor technology coupled with AI and fuzzy logic techniques significantly advanced the state of the art in measuring intangible parameters. For example, color sensing technology is one of the latest inventions in this measurement field.

AI Techniques

The intelligent sensors are used to sense process parameters in real time, on-line in order to consistently maintain product quality without human intervention. AI is extensively used to aid sensor technology in order to determine appropriate process characteristics such as physical state or chemical parameters. This breakthrough allows human knowledge of the state or parameters to be added to the sensor's memory especially dealing with a combination of tangible and intangible variables. This will enable the sensor to anticipate what is likely to happen based on the environment and circumstances. The steps involved in creating a sensor network will include data collection and sensor selection, training the model, and testing and validation [359]:

- Data collection and sensor selection is the most time consuming phase. For example in food processing, measuring of taste involves many product samples that can contain many tangible variables. The subjective judgement of human testers is to be captured within the boundary conditions.
- Training the model determines the required output based on inputs. This learning allows to determine the inputs that are affecting the output and eliminating the rest.
- For testing and validation, the model is tested and if necessary the steps above are repeated.

Communications

Sensors communicate with other devices such as actuators and controllers. With intelligence built into the sensors, the need for communication will be on a need by basis. This will the reduce the frequency and time involved in communication. This characteristic which is available today will greatly enhance high-speed processes and reduce the load on the controllers. Yesterday's "continuously sending data" type sensors may become obsolete.

KNOWLEDGE-BASED ARTIFICIAL INTELLIGENCE SYSTEMS

DESCRIPTION

Knowledge-based systems are computer programs which use a mechanism for reasoning about facts. The rules to be used and the facts are input by the person preparing the system for use. There are many methods with which the program uses the rules, with the aim of reaching the best solution as quickly as possible. In a knowledge system, the databases are replaced by collections of data and rules, together called knowledge bases.

A knowledge-based system captures valuable expertise about solving a problem and makes it available to all who need it. The computer stores, organizes and delivers the knowledge. An expert system program contains information on a particular subject, known as knowledge base, that is most frequently represented as a series of "if-then" rules, although in some systems the knowledge is represented as frames, objects, or semantic networks. Probability weights may be assigned by the knowledge engineer to the rules in expert system knowledge base. The largest and most complex systems have thousands of rules and may take two years to develop. Development of such systems take so long because, for the system to be usable, the expertise to be captured must be clearly defined, and all the steps a human expert would take to draw a conclusion must be spelled out in detail. As the number of rules goes up, the time needed to solve a problem goes up rapidly. The challenge for the field is to develop new techniques which will enable a program to solve reasonably rapidly problems with much longer and more sophisticated knowledge bases.

New methods are being developed which in the future are likely to generate higher levels of capability in this field. An important such technique is the subject of neural nets which allow a network to learn patterns of various kinds.

WHY IT IS IMPORTANT

Expert systems allow companies to preserve and document part of their knowledge before an expert leaves or retires from the organization. Knowledge-based systems allow expertise to be shared at several sites, thus enhancing distribution of the knowledge of experts. Knowledge-based systems can be used as a training vehicle, or a diagnostic system, or can be used to do routine work of an expert.

Expert systems using knowledge bases can significantly enhance productivity in industry. For example, five years ago, an electronic circuit may have contained 2,000 to 4,000 gates. Today there may be 50,000 to 100,000 gates in a circuit board. The best engineer can design an average of 200 gates/week. As a result, the circuit design process is lengthy, error prone and more expensive than ever before. Circuit designers spend more time correcting designs than developing new designs. Using knowledge-based systems, Application Specific Integrated Circuit (ASIC) design time and associated costs can be reduced by reducing design lead time from weeks to hours.

Artificial Intelligence (AI) is found in many technologies such as robotics, vision, natural language processing, neural networks, etc. Research is thriving to create machines with rudimentary ability to move, see and communicate. Currently, for example, in one such system a worker can teach the robot's "eyes" to recognize a new part in less than 10 minutes. Knowledge systems can understand simple instructions with a limited vocabulary, and so natural languages can be used as input to systems. AI techniques are making computers more user-friendly.

The rudimentary AI technique, expert systems, plays an important role in manufacturing including product design scheduling, process planning, selecting machine parameters,

group technology coding, etc. [278]. In process planning, expert systems are used for generating the process plan and CNC programs [274]. During manufacturing expert systems can be used for scheduling, material handling and simulation. In addition, expert systems are used in trouble-shooting precision machines, setting up screen printers, etc. In general, in any process with many changing variables, expert systems can play an important role.

The benefits of expert systems are well documented. Texas Instrument's capital proposal package develops capital proposals 20 times faster than the previous system [332]. The new system reduces cost overruns and preparation expenses by an average of $2 million a year. American Express' Authorizer's assistant expert system increases efficiency of its credit authorization by 45% to 67%. Du Pont has a return on investment in expert systems of 1,500% and an aggregate savings of $10 million. DEC believes it is saving $70 million a year from its 10 expert systems [393].

Expert system installations grew in the U.S. from 50 installations in 1986 to 1,500 now [332]. About 20% of the U.S.' largest companies are using expert systems and 60% are considering employing them [75]. The U.S. market for expert systems grew from $4 million in 1981 to $400 million in 1988, and may have increased to $800 million in 1990 [196].

A survey in 1988 stated that the maximum number of rules used in an expert system in Japan was 1130, by Nippon Steel for diagnostics of furnace operations, and around 100 companies were using expert systems. The total U.S. installation of AI systems then outnumbered the Japanese by 10 to 1 [84].

CRITICAL COMPONENTS

Software

The main ingredient of a knowledge-based system is software. The introduction of expert systems was facilitated by the emergence of shells and software tool kits to build them. These provide flexibility and graphic capabilities. Rules such as backward chaining and forward chaining are embedded in the software. Chaining is a method used by expert systems to proceed logically from rule to rule to reach a solution.

Human Experts and Knowledge Bases

The major asset of the firm is human capital and an estimate in 1985 notes that the value exceeds $30 trillion [30]. The asset of firms is in the knowledge of employees, which consists of expertise in various technologies, etc. If human expertise is a scarce resource needed to service many customers, the service time will go up, since few customers can use the expert concurrently. If experts are scarce, firms would like to make them more accessible. Hiring and training may be less efficient and costly. Expert systems can be used for routine expert tasks, leaving the human expert to deal with specially difficult problems. One of the factors which contributes toward expert system success is the speed and ability to serve many customers concurrently.

Parallel Computing Hardware

Hardware is a key component for the expert system. As the number of rules increases, the application will require larger and faster computers. Computers need to sort through large amounts of data. Processing the computational load in parallel can attain greater speed and cost reduction compared to mainframes and serial super-computers.

Knowledge Engineers

They are similar to system analysts, and direct the construction of an expert system. They model the expert's knowledge using various representation techniques. The knowledge engineers first lay out user requirements, then accumulate knowledge by interviews and data collection from various experts. They convert the accumulated knowledge into the knowledge base.

MODULAR RECONFIGURABLE PROCESS HARDWARE

DESCRIPTION

Process equipment, even if it can operate flexibly, is often very expensive. Examples are semiconductor fabrication processes, or multi-axis machining centers. A number of people in industry propose that a move be made to construct such machines from modular components. These modular components could be reused to upgrade systems and to reconfigure machines, to take care of changing production requirements. For instance, in a machining center or milling machine each of the machine's subassemblies would be a standard module. The table, the motor, the controller, the tool changer, and so on, would all be modular plug-compatible components.

If such components were developed in accordance with an overall generic system framework, then introduction of new process machinery would in many cases, instead of requiring a large investment for a whole machine, be accomplished with much less money by acquiring only a few modules and reconfiguring an existing machine. The present Air Force MMST project is a development in this direction for semi-conductor fabrication.

The modular reconfigurable approach to modules of process systems is not widely accepted and such modules are generally not available at present.

WHY IT IS IMPORTANT

Process machinery is becoming more and more expensive and decisions to make such investments are therefore more and more difficult. Development of modular plug-compatible hardware technology would enable processes to be installed and upgraded much more cheaply than at present.

CRITICAL COMPONENTS

Encouragement of the Requirement

There currently is not much encouragement to move in this direction and process machine manufacturers do not usually provide systems made up entirely of modular components. In order for them to do that, encouragement is required on the part of potential customers such as large industry, the DoD, and so on. Nevertheless, to reduce cost machine tool suppliers need to take a consortial approach to an industry-wide standard framework.

Gradual Investment

A move to production machines based on modular reconfigurable components cannot be made suddenly. This will require a gradual investment in this technology. The modular reconfigurable machines would have to blend into production processes with non-modular machines during a transition period which would last for a number of years.

Availability of Modular Reconfigurable Hardware Components

A move into modular reconfigurable hardware, which would lead to clear benefits nationwide, is a chicken and an egg problem. Manufacturers of process machinery will not provide such modular components until there is a demand and it is difficult to generate the demand while the production processes are based on non-modular machinery. This chicken and egg situation needs to be broken by large industrial organizations and the DoD generating firm orders predicted a long time ahead so as to encourage process hardware manufacturers to move in this direction.

Standards

If each process hardware manufacturer were to make modules based on specific standards for his company only, then this development will not be effective. In order to be effective common standards should be accepted by every process equipment manufacturer. This implies that large customers which are industry and the DoD would set standards and specifications for the modules and would demand that such modules be made available.

ORGANIZATIONAL PRACTICES

DESCRIPTION

Global competitive pressure is forcing companies to be more responsive to customers' demands for ever-higher levels of quality and diversity. Customers are also demanding more involvement and control over their suppliers. All of these pressures have caused changes in industry as signified by a high level of automation. This includes computer-aided design (CAD), computer-aided engineering (CAM), robotics, flexible manufacturing systems (FMS), etc.

Failing to understand and prepare for the revolutionary capabilities of these systems will inhibit companies from achieving the full potential of the systems. This may result in more expense or loss of their competitive ability.

WHY IT IS IMPORTANT

Organizational practices grew up in a slowly changing, almost static world of a long life of an unchanging product and a long-lived unchanged production system. Production was the slowest long-lead item in an enterprise. Today, the technical work of physical manufacturing has been modernized, and as described in this report, will not be the slow, limiting process in the system. However, the enterprise as a whole will not react agily unless the old slow organizational practices are changed to be faster reacting.

CRITICAL SUCCESS FACTORS

Team Culture

The knowledge and capability required to take advantage of opportunities in the rapidly changing business environment of the future will require that people with different capabilities team together. We previously had the concept of the "renaissance man". We now look forward to the period of the renaissance team which manages as a team from one or more companies to reach multi-functional achievements which move a company forward.

Organizational barriers and the constant desire to form special committees will cease to exist as the new environment will not have hermetic internal boundaries, thereby promoting a more responsive, cohesive unit to address pressing concerns and issues. The new environment will remove traditional labeled and pigeonholed specialists who tend to become stagnant and complacent, by encouraging multi-discipline ability which will lead to increased flexibility in addition to unlimited challenges and opportunities created in a dynamic world.

Concurrent with this new environment will be a notable improvement in employee utilization. This will occur because of the infrastructure established with and between companies which will focus on optimizing the applications of each employee's skills.

This network will make required skills easily transferable based on changing demands. This sharing of skills and work force will help reduce overhead labor rates by minimizing the need for a constant level of employment, enabling companies to be more responsive to dramatic peaks and valleys in demand, with limited resources.

As the technology enables more highly automated methods of designing, planning for and building products, the role of more and more employees will consist of "change"-oriented activity (new designs, new processes).

A necessary ingredient for success in this environment is the management and organizational discipline which enables cross-functional learning of all critical functions. Characteristics of this environment are:

- Technology to allow instantaneous and complete communication of all critical product and business data to all parties.
- Flexible and reconfigurable organizational structures will be defined by and supported by enlightened functional management.
- Reward and review mechanisms will be defined to properly recognize team-oriented behavior and successes.
- A people development process which enables complex tasks to be executed by a small number of well rounded generalists also can bring together the necessary resources and make the required decisions to bring about the new product or process. If the core team grows too large, the project becomes unmanageable.

Flatter Organizational Structure

As a company becomes more automated, the need for labor will become less. The move toward a paperless factory will change the way companies operate, from labor intensive to information intensive. There will be significant reductions in the number of indirect workers and staff. Most of the work force will be highly educated as required to operate complex systems.

A dramatic shift in both structure and business philosophy will be required to reshape a traditional hierarchical structure of many levels to a flatter structured with less levels. This transition will be driven by minimizing the requirements for specialists in all functions, and moving to more generalists who are capable of performing in many disciplines. The current organization will have to give up diversified communication and information techniques as well as remove traditional barriers driven by functional specificity. The organization's information and communication techniques will become common throughout the organization and be transportable between other business entities [148].

Human Resource Management

The work force will be more diversified because of the mismatch between demand and supply of the human resources between industrialized and developing countries. While much of the world's human resources are being produced in the developing countries, most of the well-paid jobs are being generated in the industrialized countries.

The globalization of labor will demand a new kind of human resource management with more emphasis on work force diversification and empowered individuals and teams.

For more details, see "Empowered Individuals and Teams".

Performance Metrics and Decision Making

Traditional managerial "top-down" decision making, piecemeal changes, and a "bottom-line" oriented accounting are incompatible with the requirements and unique capabilities of agile manufacturing systems. There are needs for changes in performance measurement procedures, cost accounting, human resource management, and capital budgeting. A company's ultimate success depends on how effectively it can shift from measuring and controlling costs to initiating and managing projects by using new performance measures which enhance its organizational agility [148].

For more details, see "Performance Metrics and Benchmarks" and "Supportive Accounting Metrics".

PERFORMANCE METRICS AND BENCHMARKS

DESCRIPTION

Generally a performance measurement system exists to provide a means of control within an organization. The use of performance measures is predicated on the notion that the item required is measurable, and that to form an opinion for future comparison, one needs a present accurate value, utilizing a formula which is verifiable and repeatable. In the changing manufacturing environment, decisions will be made on new factors and appropriate new measures must be defined. An appropriate set of metrics for various important enterprise criteria must be developed which will measure the new phenomena of such important manufacturing issues as:

(1) the reaction time of an enterprise, (2) the adaptability skills of enterprise employees, and (3) the flexibility of the production facilities. While each of these examples seem to suggest a reasonable enterprise metric, none of them are well defined - thus they are not metrics.

How does one measure in time, efficiency and dollars, the reaction time of a company with respect to bringing out a new product variant, a new product family, a new product area, etc.? How does one measure skills in time, efficiency and dollars? According to some skill metric? According to ability to perform a known task? Individually? In the aggregate? How does one measure flexibility in terms of dimensions of products now produced, or which could be produced, or when preparation and logistic setups are needed, or volume flexibility, or material flexibility, or reconfigurability? How does one measure cultural changes that allow constant change to take place? These are today not usually measured.

Once measures are defined and implemented, they are used to measure performance of the organization. This is done by comparing with the history of the organization, or with other organizations. The choice of benchmark can be critical to understanding where the organization stands. More and more companies are moving from benchmarking against their own history to benchmarking against the best practice worldwide.

WHY IT IS IMPORTANT

Corporate planning, expediting of orders, and both tactical and strategic decisions are made in accordance with quantification of production values. The metrics that define those values are subject to a set of reasonable assumptions which in the past has seen its share of fatal flaws. For example, one of the assumptions that used to be made was that in order for manufacturing to be done profitably, the most important factor to measure was efficiency at the factory floor. One of the ways efficiency was measured was by noting machine utilization. Therefore, if machines were running constantly, throughputting product, that was desirable and the factory was "efficient." The fact that the factory may have been piling up inventory that was costly and unneeded was ignored, or entered as completed goods - an asset on the ledger. Such cost accounting methods actually militated against both efficiency and profit. In light of this example and others that utilized flawed assumptions, it should be obvious that the ability to define and measure meaningful metrics is critical to decision making at all stages of the enterprise.

Likewise, the ability to bench mark against the best in the world, regardless of similarity to application, has yielded a measurement against which we inculcate the willingness to strive for and achieve continuous improvement. The current "quality revolution" is a prime example of this phenomenon.

Quantative non-financial and qualitive performance measures are in many instances more important than quantative financial measures. Key quantative non-financial measures are cycle time, quality yield, schedule performance. Key qualitative measures are fit to company strategic plan, research and development needs to stay competitive, etc.

CRITICAL COMPONENTS

It is essential that before new assumptions in metrics relieve the old, industry recognize that prior metrics frequently were flawed, that those that were accurate for mass production may no longer apply in agile manufacturing, and that those defective old metrics will influence decisions in a negative and non-competitive direction with respect to new competitive dimensions. Perhaps one of the most important lessons to derive from prior experiences in cost accounting is the acceptance that new metrics must be constantly challenged. A new metric established does not vouchsafe its suitability for another twenty years. If anything is obvious, it is that in the manufacturing state of constant flux, measurements must keep pace with the changes. The efficacy and accuracy of accounting devices used to measure and quantify the values of the new manufacturing must be subject to constant scrutiny if they are to serve U. S. industrial competitiveness.

Because of the unprecedented complexity of future partnerships, it is most important that legal and accounting models of such partnerships include inter-company metrics and assist in a common evaluation measurement that will aid both cooperation and competition. Recognition of the ability to share the burden of developing metrics, methods of measuring them, and the resultant bench marks will be the task of cooperating companies. Investment in this area, again through leveraging, provides the ability to increase profitability and make continuous improvements in the performance of the enterprise.

PRE-QUALIFIED PARTNERING

DESCRIPTION

In an environment of cooperation and ease of consortia formation it is important to know about potential partners in advance of the decision to cooperate.

Pre-qualified partners would be a service which provides key business information about potential partners.

Information included here which would be unique to this service deals with:

- The firm's track record as a cooperating partner.
- Skill base and categories of expertise of employees, and the annual plan to upgrade those skills.
- The response time of the company in making strategic decisions, and in responding to market opportunities.
- A description of special expertise that the company may bring to a partnership.

This is a typical service which could be provided on the Factory America Network (see elsewhere in this report).

WHY IT IS IMPORTANT

The existence of the service and database will allow enterprises to rapidly find partners with the required capabilities. This quick response capability is important in the environment of quick and quality responses to customer need. One usage of the service would be to find firms to partner with in meeting customer requests.

Beyond the need for quick reaction and qualification of partners is the need for the qualification information to make informed decisions. Thus, the availability of partnership information and metrics is in itself a key enabling factor.

CRITICAL COMPONENTS

- A definition of the type of information and metrics to be included.
- Assurance that the data is up to date and reliable.
- Completeness of the database.
- General acceptance of the need to supply data to the data service.
- A mechanism so that experience which adds to or contradicts data entries can be included.
- The ability for a firm to see and update or correct entries referring to itself.

RAPID COOPERATION MECHANISMS

DESCRIPTION

The business challenges of agile manufacturing will require resources which no one company will have entirely within itself. The competitive health of an enterprise will depend on the agility with which cooperative arrangements can be formed.

In today's corporate legal environment a wide variety of routine legal actions can be rapidly taken by following prepared models for accepted practice; for instance, standard procedures for divorce, sale of property, registering a corporation, etc. Thus we suggest a model for venture formation to allow for almost instant consortium formation.

Such models generally allow for the enterprise to customize the model within prescribed limits to meet their needs. Thus we expect to allow flexibility and maintain the quick reaction capability.

WHY IT IS IMPORTANT

The investment needed to maintain competitiveness is now larger than even large organizations such as IBM, General Motors, and even the Department of Defence (DoD) can afford. If a company cannot easily leverage its investment dollars through quick formation of consortia and other cooperative mechanisms, it will not be able to compete with companies from other nations such as Japan and Germany where cooperation is more prevalent than in the U.S.

The time and effort now required to form a cooperative arrangement is itself an impediment to the use of new consortia where they might otherwise be the first choice of cooperation mechanism.

The generic pre-competitive component of building the infrastructure for the new competitive era is very large and evolving. The ability to quickly form consortia or other cooperative arrangements to allow for leveraged infrastructure development will have a major positive impact on the amount of resources available for strategic competitive activities of most enterprises and agencies.

CRITICAL COMPONENTS

The model for instant consortia formation should have a menu of categories and options within categories to be used in the rapid formation of a consortia. Based on the type and purpose of a consortia the founders would select components from the list for use in a specific instance of the model. The items which should be on the menu are listed below.

1. **Charter and Aim of the Organization**
2. **Anti-Trust Considerations**
3. **Size of Companies and Membership**
4. **Membership Responsibilities/Details**
5. **Intellectual Property Rights**
6. **Financial (and other) Resources**
7. **Tiering Relationships between Participants**
8. **Government Role**
9. **Definition of Output - Deliverables Expected**
10. **Benefit and Equity Allocation**
11. **Term and Break-up Details**
12. **Operating Principles/Mechanisms and Resource Decisions**
13. **Staffing**

CURRENT PRACTICE

Consortia are hard and cumbersome to develop. The process is getting easier as various consortia share their start-up knowledge with those that follow.

Many consortia, such as Microelectronics and Computer Technology Corporation (MCC), National Center for Manufacturing Sciences (NCMS), Computer-Aided Manufacturing International (CAM-I) are not focused narrowly on a well-defined problem. Rather, they act as a forum to mount joint action in special interest areas as they develop, through priority setting and selection mechanisms which their members carry out.

Some feel that the significant duplication of effort, difficulty in defining specific projects and other difficulties are due to a lack of special focus and purpose on the part of existing consortia.

The main reason for not having focused, specific consortia is the start-up cost in time and legal resources. Thus, general purpose consortia try to fill both needs. "Instant consortium formation" would allow the special purpose consortium to form and meet these needs. It would also remove the reluctance to let them die when the purpose has been served.

REPRESENTATION METHODS

DESCRIPTION

These are methods for representing a product or a manufacturing process in the computer. At the simplest level this would be a method for representing the data of a product or a process; for instance, the sizes and electrical characteristics of electronic components or the dimensions of mechanical components. More advanced methods would enable storing in the computer not only the data for each of the components but storing also the data for collections of components made up into subassemblies with the properties of the subassembly, and for processes operating on that data in the context of a systematic model. The properties of the subassembly cannot be simply derived from the properties of each of the components of that assembly but must be separately represented. An advance beyond that is to represent not only the data but also the processes which may operate on that data and the influence these processes may have on the configuration and design of components. This is technology which currently is being developed in the field of object-oriented programming. The Production Data Exchange Specification Under the International Standard of Product Exchange Specification/Standard for the Exchange of Product Data (PDES/STEP) is an example of a standard based on work on representation methods. This standard will change with time as results of research in representation methods become available, and because of requirements generated by the needs of increased concurrency.

WHY IT IS IMPORTANT

Errors in design often result from the inability to furnish all of the pertinent information to the designer before he/she commits to an approach. In reality most products do not have one single designer, they have several. A suitable representation scheme will allow all parties with input relevant to a design, to unambiguously communicate one with another.

There are many alternatives to representing the properties and attributes of products and production processes. Eventually standards must establish how this representation is to be made in a way common and suitable for different application programs and different users. However, in order to derive standards it is necessary to investigate many alternative representation schemes to understand the advantages and disadvantages of each and the tradeoffs involved before selecting particular representation methods as standard methods.

CRITICAL COMPONENTS

Connection With the Past

The representation method should connect easily with accepted representation methods from the past, in order that data already existing in various computer-aided engineering, design, manufacturing and process planning systems should be easily read into the new representation. This is not easy to achieve but if achieved saves a tremendous amount of effort and expense, and minimizes error in integrating old data into new systems.

Extensibility to the Future

Whatever representation method is selected it will be necessary in the future to add new data items to it and to extend the properties of existing data items. This should be achievable without having to redesign the entire representation method. The representation method should be designed so that additions and extensions can easily be added on.

Groups of Entities

It should be easy to represent the data or the properties of subassemblies or groups of elements and assemblies of the subassemblies. The technical properties of the subassembly cannot be derived from the properties of each component even though they are related. For instance, consider an automobile engine, which is an assembly. An automobile engine has properties such as torque, horsepower, rpm, heat output and so on, which are properties of the engine itself. In the absence of a computational model one cannot derive these properties in a simple way from knowing the properties of the components of the engine, and yet they are related. For instance, if the cylinder diameter were to be changed, the properties of the engine would change. Since the properties of the whole engine are not straight forwardly derivable from the property of any of its components, the properties of the engine must be represented and stored separately. Future developments in systems science will presumably augment this capability.

Representations should include all required attributes of products and processes in a way which can allow automated consistency checking of attributes. For instance, it currently is not yet accepted practice to represent tolerances of parts in an assembly so that the combined effect of many tolerances of many parts can be evaluated [8].

Wide Acceptance

A representation method once proposed should have wide acceptance. This is not easy to achieve. There is currently much research going on regarding representation methods for various mechanical, electronic and physical products, and for representation methods for the machines in a production process, and the production process itself with all of its properties. Refer to the section on standards for more detail. Work on representation currently is fragmented and standardization is not pulled together strongly enough. However, work on representation methods and systems models, which eventually influence the standards, should be augmented.

SIMULATION AND MODELING

DESCRIPTION

Simulation software programs exist today, but the capabilities are limited to parts of the total process, considered individually, and with limited capability for those parts dealt with. Simulation and modeling capabilities, with trade-off analyses, are needed for a much wider range of problems.

For the product, programs are needed to accurately simulate every component and every subassembly of a product, and for the product as a whole. The behavior of the product should be simulated from every point of view, including strength and dynamics, heat and fluid flow electromagnetic interference, control, and so on. Coupled interactions between the phenomena should be simulated. Today, such analyses are done for each domain such as logic design, strength, heat flow, control, and so on separately. Coupled analyses are rarely done.

An important part of today's simulation system is the visualization or animation of the analyzed results. The goal of visualization is to understand computed results visually. For example, in computational fluid dynamics, the fluid motion represented in nonlinear partial differential equations can be solved using supercomputers with little approximation, then shown as a color picture.

WHY IT IS IMPORTANT

The key to competitive survival is rapid realization of a product, and rapid response to a customer's order for a specific product configuration. To achieve that, every part of the product realization and production process has to be right, first time. There will be no time for doing something, evaluating, improving it and so on, as is the case today. Simulation and modeling will provide that capability.

CRITICAL COMPONENTS

Applications can be classified as follows:

- Product design to testing: Modeling, Simulations and Visualization
- Marketing - Sales: Forecasting, Investment Decisions, Growth
- Production: Scheduling, Design, Material Handling, Control, Integration, Capacity, Storage, Justification
- Shipping: Traffic, Optimization
- Labor: Allocation, Productivity, Planning

Product Simulation and Modeling

The capability of the simulation and modeling software should be such that many analyses can be made quickly enough to evaluate trade offs between different configurations. The simulations must be sufficiently reliable and close to reality that very little real prototype testing will be needed.

Process Simulation and Modeling

Simulation will be needed also for the production process. Computer programs are needed which go beyond simulating average or overall behavior of a production line. Programs are needed which simulate the exact and specific behavior of a production system producing any dynamically changing mix of products, under situations of randomly occurring real problems, such as machines malfunctioning, people making errors, material not being delivered, etc.

Computer programs for simulation of production should go beyond a simple production facility, to deal with interacting production facilities, where the output of one is sent on demand, by "pull scheduling" to another facility as needed.

Manufacturing involves the conversion of material, energy and information into a product. The scheduling and planning of information flows has become as important as for material flows. Simulation programs are needed to model the flow of information in large systems of interconnected networks. This simulation should be able to track the progress of a unit of data from source to destination, as it progresses and competes for resources with other data in the networks. The simulation should deal with random failures in the system which require rerouting, with sudden floods of error messages in the system, and with other realistic non-nominal events. Flows of data and of material in linked production systems can be coupled, affecting each other. A data message can result in dispatch of material, or can provoke a production process. The production process can provoke sending of data regarding problems or completion of some work, and so on. The simulation should allow modeling of such interactions so that the flow of information and material can be modelled not only for the nominal correctly operating state, but also for all kinds of non-nominal conditions. The simulation should enable tracking of specific data and material, not only averaged behavior for many items.

When manufacturing a dynamically varying mix of products with short reaction times and high reliability, control of the whole process needs to be considered. There are many different processes, and many different control strategies. For instance, in continuous flow processes, if at a given station the material properties depart from nominal, one may want to look ahead to change some parameters of a downstream process. These situations require simulation capability to model them, evaluate trade offs and optimize the total process even while local parts of the process fluctuate. For discrete manufacturing processes, various control techniques are available, each with different characteristics. These can vary from pure hierarchic control, control with interaction between each station but no hierarchy, with all situations between; some hierarchy and some peer-to-peer and peer-to-other generation interaction. These control strategies should be simulated so that the best strategy can be found for a given production process. The problems found in continuous flow and discrete manufacturing are not mutually exclusive. They often coexist; simulation programs should deal with such mixed situations.

Increasing Size of Problem

The size of problems which can be dealt with today depends on the hardware capabilities. In manufacturing process simulation, PC-based simulation has very limited modeling capabilities specific to the size. For example, it is difficult to simulate a 700,000 sq. ft. electronic manufacturing facility in detail in a PC-based simulation package. Complex simulations use supercomputers. In traffic network simulation, until recently mainframes allowed only 150 links and 100 nodes. A city like Austin, Texas requires 300 nodes and 100 links. Using today's discrete event simulation packages and supercomputers, 1650 links and 700 nodes traffic network can be simulated. The proliferation of architectures and technology permits 1 billion instructions/sec today. It is possible that this will increase by a factor of 10 to 1000 in the next decade due to parallel processing, and other hardware improvements.

System Integration

All the simulation programs for a product, or process, should be operated as a single system, with easy-to-use user interfaces, as uniform as possible. Data files should be according to universally-agreed specifications so that the data generated by a program should be readable by other programs. It should be unnecessary to key data in to a program by hand, if that data had already been created by some program. That uniform capability is missing today. This requirement for interpretability will be especially important as production becomes linked and networked between different remote sites. An operator or engineer should be able to easily pick up data from a remote site and automatically feed it into a simulation at his or her site.

Knowledge-Based and Artificial Intelligence Components

The trend in today's process as well as product simulation and modeling systems is to use knowledge-based and AI-based technologies. Also, animation of simulated results in three dimensions is becoming common. Most of the commercially available packages offer post-processed animation capability. Simulation systems are becoming more and more user friendly. The process of simulation involves many steps especially when designing a future manufacturing system. The trend is to reduce the time involved in the simulation process - providing interactive graphic interfaces. Today the logic depicted in a process simulation model can be directly used to design the control system logic which can be ultimately converted into integration software modules. However, today's process simulation systems cannot exactly replicate real situations - the challenge in the future is to achieve this more and more closely.

Incremental Simulation

Responsiveness of large simulations can be improved if one can partially isolate the effects of minor changes and rapidly recompute the simulation. Examples today include incremental compilers, incremental planners and analysis programs that perform incremental remeshing. Typically, extra state and dependency information must be maintained.

Due to the scaling issues associated with complex projects, even the fastest computers will be unable to provide interactive responses to "what it" questions unless incremental methods are employed.

Program User Interface

While numerous simulation and analysis programs exist, they are generally written by specialists, for specialists. This makes it difficult to use them for providing on-line "services" that would field requests from anywhere (e.g., design, manufacturing) within an integrated enterprise.

Improvements in Hardware

Simulation capability is closely tied to progress in computer hardware and systems. It is expected that for scientific visualization, work stations with 16-32 mbyte of data will be connected in a high speed network, with the ability to transform millions of polygons per second. In the future, simulation with animation will be one of the key technologies that support total manufacturing enterprise.

SOFTWARE PROTOTYPING & PRODUCTIVITY

DESCRIPTION

Software development is the process by which user needs are translated into software requirements, requirements are transformed into design, designs are implemented in code, and code is tested, documented, and certified for use [195]. Software engineering is then defined as the systematic approach to the development, operation, maintenance and retirement of software [195].

Software productivity deals directly with the issue of reducing development time and costs, and is affected by both methods and tools. The class of tools referred to here are typically called CASE, or Computer-Aided Software Engineering.

CASE prototyping tools are a form of modeling and simulation technology that allow a system engineer to create an executable representation of a proposed interacting collection of software modules. As the design and development of software systems progresses from early conceptual ideas to specification, from there on to program coding, then to testing and debugging, and eventually to operation and maintenance, comprehensive prototyping tools assist software engineers throughout the entire cycle.

WHY IT IS IMPORTANT

The emerging agile manufacturing environment relies heavily on software control systems that are distributed across many different programmable devices in the factory.

Today, designing, implementing and testing distributed software control systems is a major unpredictable variable in the realization of a production facility. How long this will take, how much it will cost and what it will be able to deliver in the end are unknowns until the effort is finished. Today's systems efforts are generally finished when a compromise over original goals is reached in order to have something that is operational. The agile manufacturing enterprise cannot exist until this impediment is overcome.

Tools and methods are needed that facilitate software prototyping so that the system design engineers can quickly reduce design concepts to operational models that can be validated and extended. Currently these designs are done on paper in the form of a systems specification written in a textual form. Design flaws are not uncovered until a considerable amount of resources have been expended in the implementation phase. Design flaws are the most expensive to correct and are often in the systems architecture itself which frequently precludes the attainment of the original system goals.

It is shown in [211] that 56% of the errors in systems and 82% of the error correction costs are due to faulty system designs at the specification stage. Prototyping tools that execute design representations and expose flaws at an early stage when both the design and design effort are still plastic should virtually eliminate this significant area of cost and boost productivity by the time saved.

More importantly, they will eliminate the even more significant wasted time and cost associated with rework and redesign caused by implementing specifications that are typically incomplete and architecturally flawed.

System design prototyping tools capable of executing design representations should also be able to generate the code that can operate the actual system. Thus, one representation can serve as both an off-line model and an on-line system, opening the door to safe, incremental-change testing. Altering the off-line prototype when incremental improvements are suggested will test and validate these changes without jeopardizing the operational environment. Some early work in these areas is starting to appear but a lot remains to be done to further develop these concepts into usable prototyping tools.

Though software is now recognized as a critical enabling technology, development methodology has evolved little beyond an art form or craft, and lags behind other computer technologies. According to [195], the factors contributing towards the lag include:

- Poor understanding of the development process.
- Lack of tools for reducing time to market.
- Growing costs associated with development.
- Rising number and size of applications.
- Complexity and user expectations.
- Need for greater portability across platforms.
- Complex transaction-based distributed computing.
- More customization required.

The biggest and most costly problem in software design is programmer productivity. Programmer productivity is showing almost no improvement over the years compared to the 35% per year gains shown by integrated hardware designers [27]. Reusable software is one of the most promising areas for software productivity and quality improvement, and a principal byproduct of CASE technologies.

According to [366] "the most innovative and successful development will be done by two types of organizations: those capable of producing specialized tools and building blocks; and others who use those tools and building blocks to create effective applications. Only by specializing in one of these areas will companies be in a position to compete".

CRITICAL COMPONENTS

Virtual Factory Modeling Tools

"Virtual Factory" research is a promising area of systems simulation and modeling that attempts to develop a complete and accurate representation of an operating factory, whether discreet-part or continuous-process oriented. For many applications these models need to run in "real time" so that downstream processing can be adjusted on the fly when upstream modeling suggests the need for corrective action [258].

Application Program Interfaces (APIs) and Graphical User Interfaces (GUIs)

Hardware and software computing capability is provided by a multiplicity of vendors in a variety of forms. Manufacturing has emerged as one of the principal melting pots for this multi-vendor community.

To eliminate the problems arising from using computing equipment from different vendors within the same networked system, a movement has begun toward "open computing" -- the idea that software should function without change on a reasonable selection of platforms from different vendors.

Software known as an Operating System can be viewed as the first layer on a hardware computing platform. Today's popular operating systems include such names as UnixSystem V and Unix OSF/1, DOS with Microsoft Windows, IBM's OS/2, and DEC's VMS. Both OS/2 and VMS are considered proprietary to a specific manufacturer, whereas Unix, and to some extent Windows, are considered in the "open" category as they run on equipment from many vendors and are not subject to control by a hardware vendor's business strategy.

Though open operating systems have the beneficial potential of presenting a "common" interface to an application program (the program that actually does something useful for the manufacturer), and thereby allow portability from one computing platform to another, in reality there are still too many variations among these so-called open operating systems. This has led to the call for and definition of common APIs (Application Program Interfaces) for these operating systems. One such API still in its incubation phase is POSIX. With the emergence and industry-wide acceptance of a standardized API a great deal of time, effort and cost will be saved in programmer training, software development, and software porting.

Another area of current focus is the Graphical User Interface (GUI), which is a combination of the displayed image and the user interaction with this image presented by the application program. GUIs are a new concept currently that has resulted in a variety of approaches; though most are relatively similar in nature. As the industry moves toward standardization here, additional productivity gains will be realized not only by software engineers, who will no longer have to create user interfaces for each application, but also for users, who will find a common interface among a variety of different applications.

Object Oriented Programming Languages

Object oriented programming (OOP) languages, such as SmallTalk and C++, bring a very different approach to the design of software systems then the classical sequential-programming paradigm that characterizes the history of modern computing. OOP languages allow people who understand a process to express this process in ways that are understandable to computers, potentially allowing people not thought of as programmers the capability to harness computing. OOP approaches also promise great gains in there-usable software category, in the enablement of continuous evolution of functional systems (safe ongoing improvement), and in breaking the barriers that impede the implementation of complex systems.

Computer-Aided Software Engineering (CASE)

The earliest use of the CASE acronym dates to 1984 [335]. Like any other engineering disciplines, software sciences began by following a variety of different methodologies. The software engineering field is still young enough that first generation sequential-programming approaches are just now being challenged. CASE tools are introducing structured programming and object-oriented approaches, as well as disciplines that promise to change an art-form into an engineering activity. Early CASE tools have tended to bring discipline to classical approaches. More recent activity is exploring newer object-oriented and distributed-processing architectures [101].

STREAMLINED LEGAL ROLE

DESCRIPTION

Legal systems evolve as public and general opinion move toward the recognition of manufacturing enterprises as a key component of the standard of living. Movement is taking place in the laws of the country as enacted as well as the interpretation of the legal actions taken or not taken by the government with respect to the manufacturing community.

Examples of legal system interpretations and laws and their implications for manufacturing enterprises, as put together by the inner core team for this project, follow.

Relaxing the definition of "Anti-Trust" activity

Would facilitate the move towards cooperation for enterprises in consortia, joint ventures, etc.

The new and correct assumption that the government can fund and incentivize "Pre-competitive generic research", such as in the Advanced Technology Program.

Is attracting teams of enterprises who are working together in formal and informal arrangements toward common generic needs. This has caused a noticeable increase in the number of activities considered generic, pre-competitive.

Reform product liability laws and practices

Product liability laws and practices can place so large a burden on manufacturers as to inhibit development or marketing of products which could be beneficial. A better balance needs to be struck so that reasonable consumer protection will not inhibit development of useful new products.

Expanding the definition of acceptable expenditures and categories of expenditures for Internal Research & Development (IR&D) in calculation of overhead rates, etc.

Would allow management to set priorities in response to needs of the enterprise without artificial constraints. For example, this could remove the disincentive to develop manufacturing processes.

Policies which guide the distribution and transfer of federally funded technology, in government laboratories, on government sponsored or partially sponsored projects, etc.

Can impact positively the development and transfer of manufacturing processes and systems technology. A positive step would be to redefine the government position on intellectual property rights, when the government is a partner and not the sole funder of a task or project.

Import/export policies and protection of various technologies

These have a marked effect on export possibilities.

Tax laws

Tax laws do not usually assume that products are rapidly changing, constantly upgraded. As a result, their provisions often disincentivise investment in production processes and upgrades.

Trade agreements and enterprise zone definitions

Trade agreements and enterprise zone definitions will be potentially very important factors in the worldwide competitive scene through the 1990's. Careful attention and legal implications from the creation of the EEC, Pacific Rim and Latin American economic zones must be undertaken by the government. A small example can be seen in the role the Department of Commerce is now playing in the Intelligent Manufacturing System tri-lateral discussions initiated by Japan.

Foreign tax credits and treatment of foreign versus U.S. corporations

Foreign tax credits and treatment of foreign versus U.S. corporations must be investigated to ensure that U.S. corporations are not disadvantaged by our own laws.

Training and Education

The ability to put appropriate training and education expenses in capital investment categories, under certain circumstances, could be an important potential advantage to an enterprise.

To the extent that the laws consider training and education expenses to be a benefit to employees of the company, they provide a disincentive to training.

There are too many opportunities for legal actions than can be enumerated here. Our purpose in selecting the above was to show the breadth of impact and action which can be taken.

CRITICAL SUCCESS FACTORS

These factors include:

- Recognition of the fact that "Manufacturing Matters" as described in Cohen and Ziesman [66].
- An atmosphere of trust and partnership between government and industry evolving from the past adversarial

postures. This requires a shift in thinking and behavior within both parties, government and industry.

- Public perception of the linkage between standard of living and the health of the manufacturing industry, and the desire to have government act as a positive factor in the health of the manufacturing industry.
- There are no direct technological keys to making this possible. Indirect contributions may come from more comprehensive and reliable information systems which can unimpeachably provide accurate data to regulatory bodies to avoid abuse, fraud, etc. Such may then lessen arbitrary regulations put in place when such data was not reliably available.
- On the non-technological front, important keys to making this possible are significant increased understanding between legislative and industrial leaders on the true nature and impact of laws and the interpretation of regulations.

SUPPORTIVE ACCOUNTING METRICS

DESCRIPTION

Accounting, in addition to allowing historical audit of a company, provides information to support planning and controlling of operations. Unfortunately, the current cost accounting system has failed to adapt to such changes in the environment as computer-aided automation, the declining importance of direct labor, shorter product life cycles, globalized markets, and so forth. Most businesses do not have information systems that are designed to help them cope with such changes in the environment. According to Johnson [167], the solution will not be found by modifying existing management accounting systems. Those systems have their uses (e.g., to cost inventory for financial reporting purposes) but providing information to control operations is not one of them. Instead, he suggested that the solution to management accounting's lost relevance is to scrap the belief that businesses can both plan and control their affairs with accounting information that is compiled for financial reporting purposes.

Current accounting practices developed in the world of a static product and static mass production line. In many respects they are unsuited to the needs of agile manufacturing [175].

WHY IT IS IMPORTANT

Accounting provides information to support evaluation of companies. The financial community uses this information to evaluate attractiveness of the company's financial performance for investment. To the extent that accounting methods do not support measurement of relevant factors, agile manufacturing evaluations based on current conventional accounting practices will be wrong.

Accounting metrics and methods are a critical factor affecting the behavior of a company. Modernizing these are a most important requirement for the infrastructure of agile manufacturing.

CURRENT CAPABILITY

Activity-Based Manufacturing Cost Systems

According to Cooper [77], an Activity-Based Cost (ABC) system can be defined as a system that identifies and then classifies the major activities of a facility's production process into one of the following four categories: unit-level, batch-level, product-level, and facility-level activities. Costs in the first three categories are assigned to products using key cost drivers that capture the underlying behavior of the costs that are being assigned. The costs of facility-level activities, however, are treated as period costs or allocated to products in some arbitrary manner. Current cost accounting allocates all costs to direct labor which is rapidly diminishing and no longer a viable basis for relevant cost allocation.

ABC systems have emerged in companies where managers believe that the costs of the additional measurements required by the ABC systems are more than offset by the benefits the new systems can provide. Typically, there are three major benefits of categorizing activities in an ABC system [77]:

- Improve decision making due to more accurate product costs;
- Improve insights into managing the activities that lead to traditional fixed costs; and
- Easier access to relevant costs for a wider range of decisions.

New accounting methods such as activity-based accounting are slowly penetrating companies, but as additional methods, not as replacements to classical accounting procedures. A major watershed in modernizing accounting measures lies ahead. The sooner this is dealt with by all levels of society and the economy, the better. The longer action is delayed, the more problems will be caused by the lack of compatibility of accounting practices with the reality of agile manufacturing.

Environmental Accountability

Dealing with environmental problems is becoming a greater financial responsibility than before. These factors need to be included in the financial system in an equitable way [310][77].

The need for new economic measures is widely agreed. For example, there is general agreement that some global accounting system of greenhouse gas emissions is needed as part of the overall process of managing the environmental problems [392]. This is not yet an accepted practice.

TECHNOLOGY ADAPTION AND TRANSFER

DESCRIPTION

Technology adaptation and transfer methods based on an understanding of those mechanisms is needed. Technology transfer from research and development to use in production systems currently is slow and haphazard. Common methods and procedures are needed in order to facilitate and speed up that technology diffusion.

WHY IT IS IMPORTANT

Technology diffusion currently is far too slow for the rapidly changing world in which manufacturing is operating. The long time taken from research and development to implementation and routine use of new systems is a serious impediment to the manufacturing process.

CRITICAL COMPONENTS

Easy Communications

An MIT study of 102 firms in 3 countries [99] revealed that technology transfer always takes place through informal channels, with very little through formal channels and institutions. This implies that nurturing opportunities for people in different organizations to meet is important. This includes open meetings, conferences, forums, etc. Companies should see such opportunities as beneficial to the company, not as prizes to the worker.

Work Force Skills

In order to understand, adapt, improve, and use new technology the level of work force skill has to be high. The skill required to operate a static machine on a long run production line is far lower than that needed to work in the manufacturing process as machines are constantly being upgraded and improved, new processes are being brought in, and the worker in production expected to suggest improvements to the new machines and technologies which are brought in.

Empowered Individuals in Teams

Empowerment of individuals and motivation of an individual through being part of a "tiger team" generates a large amount of healthy motivation which often is lost in a strong hierarchic organization. Empowering individuals in teams will serve to facilitate the introduction of new technologies, as the team does everything it can to achieve its goal as quickly and as efficiently as possible.

Understanding of Technology Adaptation and Transfer Mechanisms

Exceptional entrepreneurs show that they have an understanding of technology adaptation and transfer mechanisms since they succeed in fact in doing that. The success of the exceptional entrepreneur is not sufficient. What is needed is that an average person in industry should be able to deal with technology adaptation and transfer in a rapid and efficient way. This requires knowledge and understanding of the factors which govern technology adaptation and transfer. These factors include individual factors, social dynamic factors, technology factors, organizational factors, and environmental inhibitors and facilitators such as accounting practices, product liability practices and so on. There currently is insufficient understanding of these factors.

Removal of Barriers to Technology Transfer

A survey [99] of 79 technology transfer facilitators showed the following serious barriers to technology transfer.

- Developed technology must be acceptable.
- Government regulation recruits and inducts technology transfer.
- Technology commercialization is not used enough as a performance criteria for development work.
- Capital requirements are often an inhibitor and cost of investment.
- The individual reward system in many companies leads to the "not invented here" syndrome because to admit that there is work elsewhere better than one's own is perceived as weakness; whereas knowledge of the whole field with the technical know how to identify, appreciate, and ability to integrate the work of others is often not rewarded.

WASTE MANAGEMENT AND ELIMINATION

DESCRIPTION

Two factors drive this. One is a growing public pressure against waste and pollution and for environmental preservation. This pressure grows as young people become older, changing societal perceptions and paradigms. The other is the growing experience of companies that recycling waste can in fact be profitable.

There is a move to place waste recycling plants at the exhaust stream of a manufacturing process, so that what was previously waste becomes a saleable product.

The long-term goal is to have zero emissions when all the waste becomes product.

WHY IT IS IMPORTANT

The fact of managing and eliminating waste may by itself be irrelevant to the agility of manufacturing. However, as populations increase and pressures are felt on all natural resources, individuals and society will not tolerate environmental damage. Environmental considerations are becoming part of the implicit value system in society, and lack of environmental concern will not be tolerated.

CRITICAL SUCCESS FACTORS

Proactive Environmental Management

Proactive environmental management is a concept which, according to Scher [307], can be defined as follows: doing what is prudent from a business standpoint to reduce environmental liabilities - regardless of whether these actions are required by regulatory agencies. The concept focuses on identifying and managing potential environmental risks before they occur or at the early stage. It is in sharp contrast to most environmental policies, which focus upon being in compliance with environmental regulations.

Proactive environmental management can be applied directly to overall waste management particularly in the areas of high potential risks such as soil and groundwater contamination, asbestos contamination and catastrophic releases of toxic materials [307].

Improvement of Manufacturing Processes

There are five distinct approaches that industry can take to reduce hazardous waste: change the raw materials of production; change production technology and equipment; improve production operations and procedures; recycle waste within the plant; and, redesign or reformulate end-products. Among the opportunities that exist for common processes and wastes are: using mechanical techniques rather than toxic organic solvents to clean metal surfaces; using water-based raw materials instead of materials based on organic solvents; and changing plant practices to generate less hazardous wastewater [157].

It is estimated [238] that American companies produce five times the waste per dollar of goods sold compared with the Japanese and more than twice that of the Germans. Waste and emission treatment currently costs about $75 billion per year [238]. A number of U.S. companies have found that by improving the whole manufacturing process to reduce waste, rather than to treat the waste as it is in an existing plant, leads to significant overall cost savings [238]. However, existing environmental legislation and existing methods of quality certification of suppliers by customers, create disincentives to change and improvement [238].

New Economic Measures for Environment

Environment and economic growth are not mutually exclusive. The new measures should aim at making environment a key competitive factor as is superior marketing, R&D, or anything else. The measures should influence value of a company's shares which, in turn, will force the company to be more responsive to environmental problems [310].

The need for new economic measures is widely agreed. For example, there is general agreement that some global accounting system of greenhouse-gas emissions is needed as part of the overall process of managing the environmental problems [392].

Recycling of Resources

According to the World Competitiveness Report 1991, the U.S. ranked 7 among 23 industrialized countries in terms of extent of recycling of resources by companies.

The top five are all European countries (Switzerland, Germany, Denmark, Sweden and Netherlands). The Japanese ranked twelfth [392].

Companies usually recycle almost all the scrap generated during the manufacturing process, but once an item has passed through consumers' hands the rates drop sharply. Only about 40% of the inputs to steel making consist of material recycled from sources outside the mill. Similarly, only about a quarter of the fiber inputs to paper mills are recycled material [294].

According to Schmidheiny [310], companies should engage in an "integrated life-cycle analysis" that takes into account the total environmental impact of the product from the production of the materials for its assembly through its useful life to the process of "demanufacturing" that breaks it down for recycling. In this manner, the waste of today can be converted into the raw materials of tomorrow.

In Germany, the automobile industry is moving toward this concept. For example, a pilot plant of Volkswagen AG is experimenting with a new system of recycling autos. Instead of using the current methods of crushing old cars into a cube containing much unwanted remnants such as plastic and rubber that must be refined out at great cost in energy to recover the desired steel, Volkswagen is dismantling worn-out autos piece by piece. By this method, even parts of the battery can be re-used. Brake fluid and lubricating oil, which are spilled on the earth in the current wrecking methods, are drained for refining and re-use. In fact, Volkswagen engineers estimate that in the future as much as 90% of the steel, lead, zinc, copper and aluminum in a car body can be recovered. The percentage of plastic being recycled is also rising dramatically [310].

Environmental Laws and Regulations

Regulatory agencies can change the ground rules for a company or an entire industry [307]. However, to be truly effective, there must be international cooperation supported by people and governments everywhere.

Collaboration between Manufacturing System and Waste System Designers

The waste problem can be greatly ameliorated if designers of manufacturing systems and designers of waste systems collaborate from the first stages of a project, rather than have the waste system designers deal with the problems created by the manufacturing system designers. This will require among other things proactive efforts by professional societies in these fields.

ZERO-ACCIDENT METHODOLOGIES

DEFINITION

The goal of process safety is to protect people, property and the environment from some kind of destructive release of energy. Zero-accident methodologies make plants and processes inherently safe; that is, safety is built into a process from the beginning, in the conceptual design level. This is as opposed to having to add safety features extrinsically later.

WHY IT IS IMPORTANT

During 1987, due to accidents, nearly 75 million workdays were lost at a cost of $42 billion [396]. Companies realize that it is harder and more expensive to add after-the-fact safety features to processes once they are already in operation. The cost is generally not only economical, but also, environmental, and unfortunately many times may involve societal calamities. Member companies of the Chemical Manufactures Association, for example, are putting finishing touches on a six-point performance improvement initiative, the Responsible Care Program, in which the underlying philosophy is that of safety considerations throughout the entire life cycle of the chemical process [146]. Another important factor is the increasingly stringent state, federal and international regulation, such as the Emergency Planning and Community Right-to-Know Act (1986), the California's Acutely Hazardous Materials Risk Management (1988), or the New Jersey's Toxic Catastrophe Prevention Act (1988).

CRITICAL COMPONENTS

Simulation & Modeling

This allows exhaustive detailed modeling of the physical processes. Currently simulations are standard in the nuclear industry, where they are required by the U.S. Nuclear Regulatory Commissions; simulation is also used routinely in other process industries: utilities, chemical, petroleum and others. With the advent of affordable and easy-to-use supercomputers, pre-production simulation of possible accidents and safety devices should be a standard step in the design of all industrial systems.

Proactive Committed Management

This means that managers go one step further than just compliance. For instance, safe processes must also consider ergonomics. The better the work station is designed ergonomically, the less accidents due to human error can be expected. For instance. Rohm and Haas Company, manufacturer of specialty chemicals, has created a corporate ergonomic program which safety and health officials see as encompassing more than just complying with future OSHA regulations [230]. Air Products' management has established a policy that makes all employees, whether in design, construction, or operations, responsible for conducting their jobs with utmost concern for safety.

Design Safety Elements to Require Minimal Human Intervention

Close to 60% of process accidents are due in some measure to operator mistakes or miscalculations. Design of safety can be accomplished, for example, by reducing system temperatures and pressures, possibly by the use of catalysts; substituting less hazardous raw material for more hazardous; and designing elements that allow the system to survive routine upsets without need for direct operator intervention. At the Olin Corporation plant in Charleston, Tennessee, for example, the highest air pressure is 225 pounds per square inch and the highest temperature is 320°F compared to some petroleum refineries that work with highly volatile hydrocarbon feedstocks at 1800 pounds per square inch and temperatures up to 1600°F [48].

Ongoing Employee Training and Involvement

Training is necessary to keep the work force's knowledge about the system up to date with the latest modifications and improvements of the processes. Involving employees in the safety process has well proven results in reducing the number of accidents. A gas producing and packaging facility in New Jersey, for example, improved from 15 critical accidents in 3 months, to working 3 years without a lost-time accident [201]. Through safety programs that involved employee members, Air Product's R&D division has had 10 years and 20 million hours without a lost-time accident [296].

Shared Databases

Statistical data on the reliability of systems, and safety techniques are shared among companies.

GETTING IT ALL TOGETHER!

General recommendations addressed to Congress, Industry, the DoD, the Executive Branch excluding the DoD, and Academia were presented in Volume 1 of this report. The recommendations given there are repeated here, but in more detail. The following pages give detailed recommendations on steps needed to put the infrastructure in place, presented in tabular form, by the five groups to whom they are addressed, and by the nine elements of the agile manufacturing enterprise.

An enormous effort is needed to put in place the infrastructure, with both technical and non-technical components, for agile manufacturing. This will require coordinated efforts of many organizations in many sectors. The study anticipates a need for coordination of these many efforts, and a need for monitoring how specifics of the vision as predicted, are seen to change as time progresses. This should accompany an overall view of how the national effort for agile manufacturing progresses relative to the continuously updated vision goal. The Agile Manufacturing Forum is the mechanism recommended for these functions. Many of the action items recommended in the following tables can be aided by taking advantage of the Forum.

ACTION AGENDA FOR

- Congress
- DoD
- Executive (Non-DoD)
- Industry
- Academia

ACTION AGENDA FOR MANUFACTURING ENTERPRISE ELEMENTS

Item	Congress	DoD	Executive (Non-DoD)	Industry	Academia
Business Metrics and Procedures	Provide predictability and stability with respect to laws and regulations which control business metrics and procedures. Facilitate by legalizing, but not mandating, appropriate measures which can evolve to meet changing business needs. Facilitate the agility of the enterprise by minimizing paperwork and other impediments to quick reaction by industry to various competitive opportunities. For example, provide a method of quickly forming a cooperative venture to take advantage of a commercial opportunity. Recognize the need for dynamic changes and alterations in the metrics and benchmarks we use and write such capabilities into the law.	Accommodate industry's efforts in this area by respecting industry's needs to dynamically alter procurement procedures and change the metrics by which it manages its operations. Examine the FAR and other regulations with an eye towards simplification, removal of barriers and providing appropriate incentives. Recognize, for example, the benefit to the government of training and education, of investment in manufacturing process R&D, etc. Insist that appropriate benchmarks and metrics be used in evaluating DoD manufacturing systems.	Utilize the Department of Commerce to keep appropriate government agencies informed of the changing business climate and industry's needs for agility and flexibility and the impact of government regulations on that capability. Take the **lead** in establishing a stable regulatory legal environment with respect to manufacturing competitiveness.	Take the **lead** in developing broad-based metrics and procedures which will facilitate managing the enterprise for agility. Participate in cooperative ventures and consortia to monitor changing needs and share the burden and risk of developing an evolving set of metrics and procedures. Pay particular attention to metrics and procedures which allow an enterprise to capitalize on its most important and flexible asset which is its employees. Develop a corporate climate and organizational structure that recognizes the competitive advantage of cooperation and the strategic value of quickly-formed alliances to meet rapidly changing needs. Provide the ability for dynamic multi-venture activities to be initiated and undertaken at the operational level when appropriate. Participate with other industry members, the DoD and the Agile Manufacturing Forum in setting up the capability to monitor and dynamically change performance metrics and benchmarks of world class operations. Work closely with DoD, government and academia in defining and developing appropriate support of accounting metrics so that decisions can be based on novel cost drivers suited to the agile enterprise.	Provide appropriate research and development support of industry in recognition of the dynamic nature of the business environment. Infuse these new elements into appropriate curricula and research at the university. Provide business metrics required to utilize enterprise integration for strategic advantage. Provide leadership in understanding the ability to cooperate and compete simultaneously and how those capabilities can be used to strategic advantage. Develop models in simulation capabilities that allow for testing of metrics and benchmarks, updating the need for changing their values and usage. Work closely with industry and DoD in monitoring world manufacturing practices and in setting changes in place.

Item	Congress	DoD	Executive (Non-DoD)	Industry	Academia
Communication and Information	Mandate the creation of a national communication and information exchange infrastructure. This will be a key critical enabling system for competition in the 21st century. The infrastructure created by this mandate should allow for information exchange with simplicity comparable to today's telephone communication. The band width and speed requirements for this infrastructure will continue to expand at a rapid pace for the next 20 years. Therefore capacity and speed should be significantly greater than today's need or that of the 1990's.	Articulate the requirements with respect to enhanced manufacturing benefits to the DoD of a communication and information exchange infrastructure. Provide DoD participation and funding to develop the infrastructure in a way which will be commercially viable. Partner with industry in defining requirements, standards, etc. Take a proactive role in facilitating the earliest possible development of this infrastructure, working with the Agile Manufacturing Forum to do so. Continue generic research in enabling subsystems for communication and information for DoD manufacturing applications needs. These include distributed databases, enterprise integration, standards, Factory America Net, human-technology interface systems, and others. Develop and participate in a center or centers of excellence for promoting the role of enterprise integration providing maximum benefit to DoD responsibilities.	Actively **lead** and catalyze the rapid development of a broad-band network as the key element in a national communications infrastructure. Provide leadership in organizing various government agencies and factors to ensure the rapid and complete creation and deployment of a communication and information exchange infrastructure. Provide a mandate to NIST to take the lead in articulating the benefits and transitioning such an infrastructure to commercial viability and self-sustaining mode. Take an active role in setting international and national standards that enable the development of enabling subsystems for communication and information. Provide continued and increased participation by the NIST groups working in enabling subsystems for communication and information. Provide **leadership** through NIST for increasing the national importance and activity in infrastructure standards and facilitating the U.S. interest in the way they are defined.	Take a **lead** role in defining requirements and providing commercial incentives for the development of a global broad-band network. Take the **lead** in organizing cooperative R&D on enabling subsystems for communication and information. Develop requirements definitions for enterprise integration and its implied infrastructure. Communicate the strategic impact of such a network on the manufacturing health of industry and the nation, to Congress. Provide cooperative mechanisms and organize an industry advisory committee which will work in partnership with appropriate government agencies to develop specifications for the communication and information infrastructure. Represent U.S. on international standards making bodies and protect the competitive interest of U.S.-based companies by ensuring easy access and transition of the current U.S. information infrastructure to the new one. Work closely with academia to simplify the architecture and make it reliable and expandable, and to develop practical solutions implementable in the near term while evolving to broader based capabilities.	Cooperate with industry and government in developing standards, required R&D, and acting as a source of expertise on technical problems. Partner with industry and government on practical developments in the critical research area of distributed databases. Develop a multi-year research agenda with usable by-products rapidly available. Make research and development on all facets of enterprise integration a priority item and coordinate the efforts of business and technical researchers in this area. Develop an appropriate research foundation for Factory America Network and the underlying infrastructure. Provide appropriate evaluation metrics, research, development and other expertise needed to facilitate rapid development and deployment of the agile manufacturing infrastructure.

Item	Congress	DoD	Executive (Non-DoD)	Industry	Academia
Enterprise-Wide Concurrency	Adjust laws having a negative impact on metrics which promote concurrency.	Explore the impact of concurrency and concurrency elements in reducing the development time for weapon systems and the remanufacturing customization of existing DoD supplies. Identify specific technological infrastructure elements which will help speed up currently sequential and unmanaged activities to provide the benefits of agility achieved through concurrency for the DoD. Work with industry as an active partner in the technological developments necessary to enable concurrency. Accommodate organizational changes required by industry for concurrent operations and make similar adjustments in DoD organizations, regulations, etc. as appropriate. Provide the leadership for the government in defining manufacturing requirements for enterprise integration. Work closely with industry in defining and developing important representation methodologies. Adjust requirements for paperwork and eliminate other out-of-date methods.	Provide appropriate changes in government regulations, metrics, etc. to recognize the speed with which agile industry will now be operating. Help provide an understanding to the lay public about the importance of increased capability achieved through concurrency and agility made possible through concurrency. Take advantage of the Agile Manufacturing Forum for this purpose. Provide significant funding for R&D through NIST and other appropriate agencies for enabling subsystems to concurrency, including distributed databases, enterprise integration, simulation and modeling, representation, standards, groupware, and others. Take the lead in this important area and expand its role significantly. In particular, it should focus on the development of national and international standards that will facilitate required moves towards agile enterprise activities.	Make a concerted effort to take the **leadership** in examining opportunities for concurrency in the enterprise. Identify technological and organizational requirements to facilitate the concurrent enterprise in achieving agility. Take the lead in partnering with industry and academia in meeting the technological challenges in implementing organizational changes. Develop coordinated consortial approaches that will produce a staged set of enterprise integration capabilities. Significantly increase the use and analysis conducted through simulation and modeling. Work closely with academia and those providing the capabilities to better understand current and future requirements. Devote significant resources to developments in this area.	Provide a source of ideas and resources in response to meeting technological and organizational business practice changes required to facilitate concurrency. Partner closely with industry in developing concurrency elements and introduce the subject into engineering and business curriculum. Provide technical strength and R&D activities on standards such as PDES, STEP and CALS. Take the lead in developing simulation and modeling capabilities to meet industry's needs.

Item	Congress	DoD	Executive (Non-DoD)	Industry	Academia
Cooperation and Teaming	Adjust laws and regulations to recognize the positive competitive reality of simultaneous cooperation and competition. Facilitate dynamic cooperation among enterprises by the development of legal models which can be configured to meet specific cooperative needs (similar in concept to models used for wills, registering a corporation, etc.). Facilitate cooperation by making long-lasting and clear rulings with respect to the interpretation of the anti-trust laws. Provide legal recognition and form to the "virtual enterprise", rapidly put together to take advantage of a commercial opportunity. Note: The "virtual corporation" will disband when the opportunity passes. Make sure there are no laws or regulations that inhibit the sharing of technology for R&D and production purposes.	Examine the role of DoD as a partner, sometimes taking the lead, sometimes being one of many, as a means of significantly leveraging DoD resources. Facilitate cooperation and the preservation of DoD interests in industry developments by accepting partnership responsibility and membership in evolving consortia. Organize and participate in cooperative ventures with industry and academia in developing enterprise integration capabilities and support infrastructure. Define DoD manufacturing community Factory America Net application requirements and support their development through cooperative efforts with industry and academia. Encourage and recognize the competitive advantage of dynamically created multi-ventures in meeting focused objectives.	Facilitate an understanding of the importance of cooperation and team work as a natural part of the American culture and way of life. Provide incentives and leadership in the development by industry of Factory America Net applications which take advantage of these two unique American strengths. Define an appropriate legal status for "virtual enterprises" formed in response to particular opportunities and needs. Provide the leadership to recognize the United States' inherent natural ability to dynamically form partnerships which cross cultural lines. Take steps to make this a national competitive advantage, in coordination with The Agile Manufacturing Forum.	Work in partnership with appropriate government executives to create an atmosphere of understanding and trust and remove the notion of industry- government antagonism. Take the **lead** in initiating requirements for quick-forming cooperative ventures. Articulate the problem with respect to easing regulations which inhibit cooperation. Define the need for tools in the technological and organizational area to facilitate cooperation and work in concert with others to achieve solutions to this challenge. Cooperate through consortia and other mechanisms in the development of the required organizational changes, training, education, and technological aids to facilitate the widespread use of empowered individuals. Define Factory America Net applications and develop them through cooperative agreements, consortia, etc. Accelerate the development of this capability and assign it a high priority because of its critical enabling role in providing enterprise agility and the ability to integrate across corporate lines. Identify subsystem requirements for support of team activities.	Provide resources and information, partner with government and industry as appropriate, and work on the development of cooperative tools. Provide leadership in developing strategic business application uses for Factory America Network applications.

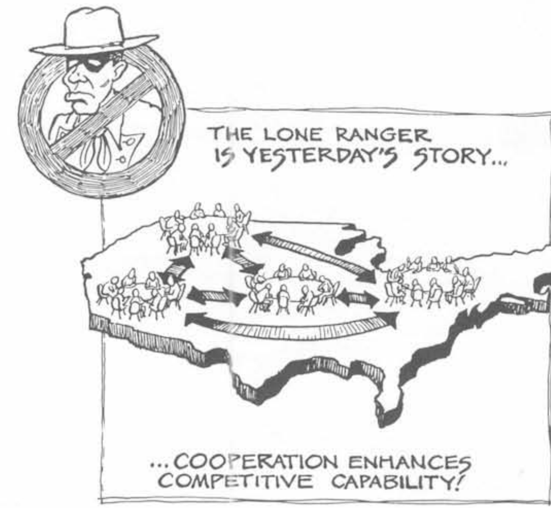
Item	Congress	DoD	Executive (Non-DoD)	Industry	Academia
Environmental Enhancement	Recognize the corporate responsibility that industry is now willing to undertake. Facilitate the care and concern for the environment by industry by providing for uniform environmental regulations across the United States, simplified legal compliance so that most of the investment can be in protecting the environment and not dealing with legal problems in the agreement. Dealing with legal problems in providing protection for U.S.-based competitors from those foreign competitors who ignore environmental implications and pollute the world we live in. Provide funding and mandate the continued development of alternate fuels and energy conservation practices.	Encourage and cooperate in the development of environmentally benign manufacturing. Allow for reasonable expense in protecting the environment and act responsibly with respect to the environment.	Recognize the responsible attitude towards the environment by corporate citizens and help them to make it a part of the corporate culture and eliminate the need for arbitrary metrics in environmental laws. Provide **leadership** in making energy conservation an important national agenda item. Recognize with appropriate awards and other incentives the achievement of zero-accident methodology on a current and ongoing basis.	Accept environmental concerns as a corporate responsibility, independent of particular laws and regulations in any locality. Treat other corporate citizens who are not environmentally benign as untrustworthy corporations who would not be viable partners. Invest with others in speeding the pace of environmentally benign manufacturing. Make energy conservation an important component for process and product design. Take steps as appropriate to significantly increase the scientific management and elimination of wastes by developing zero discharge processes.	Provide appropriate R&D in developing environmentally benign manufacturing capabilities. Work to improve process methods and control to the point where zero-accident methodology is a practical reality.

Item	Congress	DoD	Executive (Non-DoD)	Industry	Academia
Enterprise Flexibility	Provide for appropriate use of metrics of flexibility of a corporation. For example, in SEC reporting, include metrics on employees as an asset, etc.	Catalyze the development of flexibility elements at all levels of the manufacturing pyramid. Take the lead in identifying the benefit and savings available from appropriate use of flexibility in weapon systems development. Use this to develop requirements for flexibility elements which can be pursued in joint with industry and academia. Explore in partnership with industry the impact and benefit of investments in subsystem technologies in order to prioritize, including human-technology interface systems, integration methodology, intelligent control and sensors, modular reconfigurable process hardware, software prototyping and productivity, standards, knowledge based on artificial intelligence systems, and others. Facilitate the use by DoD suppliers of intelligent control systems as a method of providing higher quality and better reliability of product while reducing the time and cost of manufacturing. Provide appropriate incentives for manufacturing suppliers of DoD weapon systems to put reconfigurable process systems in place because of the savings they will provide over several weapon systems.	Mandate the use of enterprise integration capabilities with suitable modifications for government operations. Ensure that technical developments and standards take account of the full picture of the whole enterprise being flexible, and avoid optimization of single processes or standard to the detriment of the efficiency of the whole enterprise and interconnected companies.	Take the **lead** in developing new ways of using flexibility for competitive advantage in everything from how the products are produced, designed, developed, marketed, etc. Flexibility is the enabling tool for the agile enterprise. Industry must figure out what technological and organizational challenges it faces in using flexibility to enable the agile enterprise. These developments should be generic in nature, shared broadly across industrial elements, and partnered with the DoD. Work with academia to understand the technological possibilities and define ergonomically sound interface mechanisms. For example, voice recognition systems will require more than simply substituting keyboards for the input mechanism as they allow a whole new range of applications and requirements. Work closely with academia to extend the range of applications for intelligent sensors. Define methods of embedding them in processes and products to provide the benefit in reduced errors, increase capability of control systems, more adaptability and dependability of products over their lifetime in the field, etc. Take the lead in determining requirements and specifications for modular reconfigurable process hardware.	Academia plays a role in providing ideas, carrying out joint R&D with industry and DoD, and identifying new opportunities for flexibility throughout the enterprise activities.

Item	Congress	DoD	Executive (Non-DoD)	Industry	Academia
Human Elements	Accommodate and facilitate industry's move in the direction of recognizing the value of the human element by appropriate changes in labor laws and other regulatory policies. Accommodate and facilitate continuous education with appropriate tax treatment & regulation.	Accommodate industry's move in this direction and explore the role and benefit and implications of increased dependence by DoD on the skill base of its people. Examine the opportunity provided by agile manufacturing to allow the ability of people to increase the effectiveness and decrease the cost of DoD weapon systems. Participate as a partner in joint development of curricula, skill profiles, train the trainer efforts, etc. Remove the barriers in FAR and other regulations to continuous education as a legitimate activity. Design and develop methods of using empowered individuals and teams in appropriate DoD manufacturing operations.	Take the lead in identifying this country's most valuable natural resource as the skill base of its people and their participation in the competitive work force. Make the skill / educational base of the nation's work force an issue of national pride. Provide appropriate incentives and leadership to encourage education, careers in manufacturing, understanding of the benefits of team work and the natural capability of this nation to put together teams and task forces to meet a competitive challenge. Co-sponsor with industry appropriate technologies to enable continuous education, etc. Make the cultural shift from the individual as the competitive unit to empowered individuals in teams a matter of national pride and strength.	Take the **lead** developing methods of empowering individuals in teams to take advantage of team opportunities. Clearly take the **lead** in determining ways to increase the benefit to the enterprise of its most valuable resource -- its people. Take the lead in defining the requirements for a competitive work force. Put in place training and continuous education programs, empower individuals in teams, metrics and measures that reward cooperation and sharing of ideas throughout the enterprise. Make the objectives and challenges facing the enterprise clear to the people in the enterprise to get their perspective on how to increase the competitiveness of a company most effectively. In concert and cooperation with other industry, the government and academia, develop organizational and cultural change requirements, common training and education, methodologies, and appropriate technologies to aid people in carrying out their task. Partner with academia to define both the delivery approach and delivery for continuous education programs.	Provide inspiration, research, development, appropriate metrics and partner with industry and government in making people a competitive factor in the agile enterprise. Accept the responsibility to carry on activities in the continuous education area. Build a long-term infrastructural capability to meet the training and continuous education needs of industry and government as they continue to evolve. Embrace the concept of empowered individuals in teams by motivating students to be prepared to act as a professional member of the team. Take the lead in investigating ergonomic approaches to make significant breakthroughs in the man-machine interface area as opposed to incremental improvements in the use of keyboards, etc.

Item	Congress	DoD	Executive (Non-DoD)	Industry	Academia
Subcontractor / Supplier Support	Take steps to support the supplier manufacturing community in installing the technical infrastructure and equipment, training needs, and functional restructuring required as they make the transition to agile manufacturing. Be aware of the need of transition to agile manufacturing and the dangers, especially to small supplier companies, in that move. Take steps to protect the health of our smaller suppliers. Take the lead in establishing a tone of excellence and providing appropriate recognition and awards for U.S.-based industry. Provide a mandate and significant funds for national representation on international standards making bodies to adequately reflect the need of U.S.-based industry on infrastructure standards.	Take the lead in strengthening DoD's links and relationships with its suppliers and their suppliers, etc. Develop the requirements for technological and organizational capabilities which will reduce the time to develop weapon systems and make their development more effective and lower in cost. Ensure that appropriate standards, training, education and other shareable developments in strengthening supplier networks for DoD requirements are included in shared solutions being developed by industry through partnering with industry. Work with the Agile Manufacturing Forum for this. Study, for example, the impact of quick reaction products, modifications, and customizing on: logistics; inventory levels; battlefield options; graduated mobilization; operating budget, etc. Work closely with industry to develop a unified DoD/industry set of standards for the important infrastructure issues, e.g. CALS, PDES, etc.	Augment the strength of America's information technology and massively diversified supplier base. Put in place at the Commerce Department and other agencies mechanisms which will represent the smaller suppliers who are the backbone of the American industrial base. This representation should be in appropriate standards, activities, infrastructure developments, and cooperation mechanisms. Represent and protect the interests of small businesses in the development of practices for sharing technology and for taking other steps to make technology affordable.	Take the **lead** in developing highly responsive and effective supplier, subcontractor networks and capabilities with the other members of the broad-based industrial sector that has the same problem. Take the lead in establishing routine methods of sharing, not only the R&D in developing technology, but also generic shared production facilities, and providing access to modern tools and techniques in supplier networks. Develop cooperatively education and training, standards, representation, and other technological tools necessary to decrease the cycle time in developing products and the time to respond to customer orders. Participate actively with government and academia in the development of infrastructural requirements and seeing to it that they become commercially viable to support supplier/subcontractor communications and electronic information exchange. Develop customer interactive systems as a means of partnering with customers. Use them to penetrate multiple tiers of supplier relationships. Provide significantly increased participation in national and international standards making activities.	Work with industry in conducting R&D, and identifying education and training requirements. Provide objective representation for various parties in developing cooperation mechanisms, and acting as a center of excellence for small and large businesses.

Item	Congress	DoD	Executive (Non-DoD)	Industry	Academia
Technology Deployment	Eliminate legal barriers that prevent joint R&D and cooperative ventures from continuing through to successful demonstration on production floor. Take steps to emphasize the importance in cutting down the time and cost of technology adaption and transfer throughout the government.	Take the **lead** by catalyzing action in partnership with industry to drastically reduce the time from laboratory feasibility to fielded reality. This will reduce the time for weapon systems development and requires the leadership of the DoD. After establishing the momentum, DoD can and should be only one of the partners guiding these efforts to meet their collective and generic needs. The Agile Enterprise Forum, and various industry consortia and cooperative groupings such as NCMS, MCC, Sematech, etc. can be instrumental in accelerating technology deployment. Provide appropriate incentives to reduce the time and cost of technology adoption and transfer. Increase the ability of sharing DoD-inspired benefits with a commercial sector.	Fund basic research in support of technology transfer, focusing on the reduction of time to transfer technology Work with other government agencies in developing methods of shortening technology adoption and transfer time and transferring government R&D to industry.	Participates as a partner with DoD and shares leadership and funding. Exploits the generic/non-competitive nature of this activity and develops partnerships which include DoD and academia to make rapid progress. Take the lead in working with others to determine impediments to technology transfer and adoption. Examine new opportunities to use management of technology and other scientific methods to drastically shorten the technology transfer time.	Do the research to understand the problem. Participate in consortia focused on developing and evaluating rapid technology deployment and transfer mechanisms. Recognize industry's need for academe to play a high level role in the evolving partnership. Work with industry and government to find ways of increasing the capability of technology without requiring complete reinvestment. Expand the capabilities of management of technology and other scientific methods to apply to the reduction in time and cost of technology transfer.



During the course of this work it became clear to the participants in the study that evolution into agile manufacturing will require cooperation between teams within and across corporations, in unprecedented scale and intensity. This is an especially important point in the U.S., where cooperation between companies is less developed than other countries. As shown in Appendix C, the U.S. ranks only tenth in the world for cooperation between companies in R&D. This insular characteristic must, and will, be changed.

Entrepreneurship, competition and rapidly developing opportunities will create situations where any one company, however large, will not be able to marshal the resources needed in time to take a wave of opportunity. Competition will require cooperation.

In the era of agile manufacturing, many mission-oriented teams in a corporation will be at work. Every day teams will be created and teams will be disbanded. The methods and mechanisms of teaming will be many and varied.

The participants in this study, from a cross section of industries, with ample experience in the subject, were of the opinion that too few cooperation mechanisms are known, and that the serious barriers to cooperation that currently exist, but which should be broken down, should be aired. Accordingly, they identified cooperation mechanisms which need to be nurtured and developed, and identified barriers to cooperation and methods which facilitate cooperation. These are detailed in the following sections:

- Examples of Known Cooperation Mechanisms
- Factors which Facilitate Successful Cooperation
- Barriers to Cooperation
- Comparison of Old and New Practices in Handling Manufacturing Business Relationships

SOME EXAMPLES OF KNOWN COOPERATION MECHANISMS

The study brought forward the fact that there are many more types of cooperation mechanisms used than is generally realized, with new mechanisms constantly developing. These mechanisms identified by the study are given below. Other mechanisms exist and are constantly being developed. Note that although unusual today, cooperation will be pervasive tomorrow, and the mechanisms listed here will find much more use than at present.

CENTERS OF EXCELLENCE

Organizations which have been established to excel in a particular technical area. They can be established and funded (in whole or part) by government entities or may be totally private.

Over time, certain locations within a company have worked on a particular problem, or in a specific technical field, long enough that they have become experts on this item. They have become known as the place to contact when a problem arises that the normal skilled individuals at other locations cannot resolve. These centers make their skill and knowledge available for others to draw upon.

CONSORTIUM

A group of companies that have organized to pursue a common purpose, and in doing so have formed a third separate organization as a performing body.

It usually involves pooling of resources for the mutual benefit of the participants. As compared with other forms of combination, such as joint venture or partnership, a consortium is more likely to have multiple participants and the tasks are more likely to be ancillary to the main business of the participants; e.g., a consortium of computer manufacturers to buy silicon in bulk and thereby spreading the cost savings amongst the participants.

Effective only when a member is actively involved. Contributes agenda items, does required outside preparation, attends meetings regularly, etc. Passive participation yields little, if any, benefit.

JOINT VENTURE

A union of two (rarely more than three) companies that pursues a common purpose, usually for profit. The joint venture can be managed by any member company or may be a third organization that was purchased or established for that purpose. The investment can vary between company members, as can voting rights and profits.

Joint ventures tend to be broader in scope and duration then teaming agreements. Joint ventures may be implemented through contractual arrangements or by forming entirely new companies.

Permits more effective control of work agenda but also requires a greater commitment of company resources. Partner selection should be done carefully so as to avoid conflicting interests as much as possible. Difficult to achieve a mutually productive relationship.

LEADER - FOLLOWER

The concept of a leader-follower contract involves a situation where the government desires to establish a second source. Where contractor "A" is immersed in a program, the government will designate "A" as a mentor to contractor "B". When contractor "B" is brought up to speed with the contractor "A", the government will have both contractors in direct competition with anticipation of recovering the government's investment with lower costs in the long run.

NETWORKING OF INDIVIDUALS FROM COMPANIES

An informal grouping of individuals who have formed a communication vehicle to share or transfer information. The communication modes can be memos, conference calls, meetings or computer linkages. The investment required is minimal, or none. The effectiveness is largely determined by the compatibility and professional respect among the individual members. It can result from contacts initially made through various professional societies.

As today's information systems grow at a rapid pace, it is becoming possible for individuals within a company to communicate very rapidly over vast geographic distances. Satellite systems and fiber optics allow for almost instant data exchange. Computer terminals installed at the home of the employee provide 24hr/day, 7 day/week access. This has provided for some corporations a means for employees with common interests and problems to form loosely coupled "networks" for data exchange by use of the information system.

PARTNERSHIP

This term is used broadly to describe any joint activity for the mutual benefit of the parties. It is used more to describe an attitude than any specific arrangements, i.e., we are partners with our vendors, customers, etc. Almost all forms of combinations from mere information exchange to joint ventures fall under the partnership category. This word also has a legal meaning, which involves an agency relationship and profit sharing, but which is more narrow than its common usage in the company.

A new development is the concept of individual companies, each with certified performance quality, linked by a computer network for transmission of technical and business data. These companies jointly take contracts of a scope more than any one could manage separately. To the customer they appear as one functional company, but each retains its identity.

TEAMING AGREEMENT OR ASSOCIATES

Two or more companies with complementary resources combining together to address a particular contract requirement or proposal. Usually limited to a particular proposal as opposed to a broader business area addressed by joint ventures. Once the business is won, the business is usually divided according to prime contract/subcontract arrangement.

These agreements are characterized by detailed, formal documents that spell out in elaborate details the responsibilities of each party. Each party retains its own corporate entity and funds its particular portion internally, with the ultimate payback coming from profits from the sale of the hardware.

TRADE AND INDUSTRY ASSOCIATIONS

Organizations formed to specifically advance and safeguard the best interests of its members, who are all pre-qualified to you by virtue of their common business purpose. The association is a separate corporate entity, usually non-profit, that is funded and operated by member companies.

Cover the full range of activities. Some productively advance the profession and positively contribute to it; others are little more than lobbying agencies.

VIRTUAL COMPANY

A virtual company is a legally incorporated entity, from that point of view it is a regular company. However, there are almost no employees or inventoried resources in the company. The work needed, marketing, sales, design, production, and so on, are done by shareholder companies, contractors or partners. The small headquarters staff deals with few general subjects, such as planning strategic directions and new affiliations, or monitoring contributions in kind by members and the attendant payment. An example is the Visa company which has a very small headquarters staff. Although the cardholder imagines one big corporation behind the name, the work is done by many banks, clearinghouses, collection and other organizations, all using common standards to enable a seamless operation which looks monolithic to the cardholder.

In the future, we may expect virtual companies to be formed and disbanded rapidly. This will require:

- a prequalification method, analogous to ratings given now to companies;
- standard agreed business and operating methods to facilitate quick plugging together of teams from constituent companies;
- a definition of the business opportunity to be jointly pursued;
- sufficient depth of resources among partners to be able to assign valuable people and resources to the virtual company; and,
- Factory America Net industrial value-added computer network.

VOLUNTARY INFORMATION EXCHANGE FORUM

Similar to networking of individuals from companies, but the word "forum" implies that a meeting or convocation is the communication mechanism.

These forums can be ongoing via the electronic information networks, or meet at specific locations on specific dates, or a public "bulletin board" on the electronic network where data items and questions are listed and responded to. Papers can be presented and discussion follow on various topics in the latter case.

FACTORS WHICH CAN FACILITATE SUCCESSFUL COOPERATION

The participants identified a number of factors which can facilitate successful cooperation between companies. These are listed below.

CHANGE PARADIGM SO COOPERATION IS THE DEFAULT, NOT GOING IT ALONE

For cooperation among companies to occur, someone in each company must be committed to seeing to it that it happens and is sustained. The rewards for cooperation, i.e., no legal hassles, increased market share, technology leadership, world class capability, will make this cooperation occur naturally with no forcing function if the fear of legal problems and loss of proprietary data is removed.

DEALING WITH INERTIA AND PERPETUATION OF MYTHS IN THE FACE OF CHANGING REALITY

Look at things as they actually are, not as you wish they were. Too many top managers live in a world as they wish it were and don't acknowledge the problems that must be solved.

DYNAMIC RELATIONSHIPS SHOULD BE FREE OF TRADITIONAL LEGAL ENCUMBRANCES

In order to bring a joint venture or consortium together, a few days is needed to decide on how to do the arrangement, but usually three to six months is needed to work out the contracting vehicle. This is due to fear of prosecution and/or loss of trade secrets or proprietary data. Take away the legal hassles and new relationships will be formed in days. This can be vital in being able to respond to a new opportunity quickly enough.

The basis of a relationship must be mutual trust, not a lengthy detailed contractual agreement. Agreement should cover basic elements only and should attempt to avoid restrictions on every conceivable "what if".

EMPHASIZE LONG-TERM BUSINESS VIEW

Requires a reorientation of most top management. Pressure to achieve near-term profits is counterproductive to this. It is desirable that business practice decrease the emphasis solely on quarterly reports, and give weight to long-term programs. This will encourage high-level executives to think in longer time frames.

EMPHASIZE NEED FOR SPEED

The requirement for speedy reaction to a window of opportunity is a prime driver to cooperation.

EVOLVE A STEP AT A TIME

The drivers and influences on the manufacturing enterprise will move companies to pervasive cooperation. To the skeptic, this appears overwhelming, but it will develop a step at a time.

FLEXIBLE BUSINESS ARRANGEMENTS TO BE ACCEPTED AND COMMONPLACE

While teaming arrangements, joint ventures, etc., are becoming more commonplace, they need to be an accepted way of doing business. Both industry and government need to accept the fact that no one company can, necessarily, have all the resources or be the best in all areas to enable them to be world class in an industry. Often it will require unique cooperative business arrangements to bring on new technologies and products, and these arrangements need to be accepted rather than suspected. This will be very important in the defense electronics and semiconductor industry as the costs of introducing new technologies continue to spiral. Being allowed to protect proprietary data while sharing the bulk of technological resources free from government anti-trust threats will be key in the future.

Suppliers must demonstrate their trustworthiness for this type of mechanism to work. While it eliminates placement options, early commitments can provide major advantages in product development.

GOVERNMENT REQUEST FOR PROPOSAL TO GENERATE ACTION

A request for proposal by government, with a declaration that joint industry proposals will obtain tangible financial incentives, encourages cooperation.

INDUSTRY ASSOCIATION REQUEST FOR PROPOSALS TO GENERATE ACTION

Industry associations can encourage cooperation by requesting appropriate proposals and making financial awards to the winning proposals.

Experience shows that even when a bidder is unsuccessful, it has been able to make successful unsolicited proposals to other parties and capitalize on the efforts of bidding on a request for proposals.

INTELLECTUAL PROPERTY SHOULD BE MUCH MORE SHARED THAN IN THE PAST

Intellectual property will be shared more readily when companies are compensated for that sharing, and the rewards, such as increased market share, new markets and reciprocal intellectual sharing make it a poor business decision not to share. The system now discourages intellectual property sharing because the losses can be enormous with little opportunity or assurance for long term financial reward or pay back. When the rewards are greater than the penalties, then sharing will occur.

VIEW SHOULD BE COUNTRY-WIDE, VALUE-ADDED

There are two issues involved here. One is the concept that all critical technology components of any program need to be U.S. based, and the second is that in addition to being the world's best inventor, we need to capture the manufacturing base or production base for that idea. Manufacturing is key to our long term survival as a nation and must be nurtured like any natural resource. IR&D money must be directed, not only at inventing new technologies, but pushing them into production as well. Everything from patient capital to a favorable environment for consortia must be brought to bear to insure that we can produce what we conceive and that we maintain a production base in this country.

BARRIERS TO OVERCOME FOR COOPERATION

The participants identified a number of barriers which must be overcome, in order to achieve cooperation.

CULTURE GENERATES NIH ("NOT INVENTED HERE") RESISTANCE

Encourage adopting other people's initiative and building and adding value to other people's ideas. In many organizations one's personal advancement is still perceived to be achieved by doing exactly the opposite of the above.

GEOGRAPHIC SIZE OF U. S. AND HENCE TRAVEL INHIBITIONS

Communication improvements are steadily making this a less significant impediment. Continued improvement in communication will enhance cooperation.

LACK OF KNOWLEDGE OF OTHERS

This is an organizational intelligence problem and communication problem. A systematic and serious effort should be put in place to know what other groups in one's own company, and in other companies are doing, with a view to using cooperation as a method of first resort in a project.

LACK OF TRUST

Building trust requires:

- Top Management Involvement
- Mandatory Multi-Level Communication and an Open Agenda
- Common Training
- Common Expectation of Improvement
- Common Recognition of Achievement

Trust must be earned.

LACK OF UNDERSTANDING OF WHAT CONSTITUTES COMPANY PROPRIETARY OR PROFOUND KNOWLEDGE ("FAMILY JEWELS")

Management often does not appreciate the value of external capabilities to its operation. Often, management regards knowledge of some process or material as important proprietary knowledge; in fact, a case can often be made for sharing the cost of developing a particular process, and using the resources made available to deal with other problems, with a view to making the whole system more efficient.

LEGAL IMPEDIMENTS

The time and cost of the legal process is often a factor which nips cooperation in the bud. Technical managers often tend to frame an action plan agreement within a few days, and imply trust between them. The lawyers assume lack of trust, and can take months to come to an agreement.

ORGANIZATIONAL COMPARTMENTALIZATION

To encourage more expansive thinking within the organization, reward and promote those who best communicate and deal with the big picture in order to identify opportunities for collaboration.

PATENT SYSTEM

The time, expense and disclosure methods currently in practice inhibit cooperation. Making the patent process more efficient would facilitate cooperation.

REWARDS DON'T RECOGNIZE GROUP, EMPHASIS IS INDIVIDUAL

Group rewards should supplement individual rewards regularly to encourage team efforts. You don't have to lessen individual initiative -- you just want to encourage cooperation and sharing.

TRADITIONAL BUDGETING INHIBITS FLEXIBILITY/QUICK REACTION

Flexibility is the key to success in this area. Give a manager responsibility and a budget total that he must live with, but let him exercise judgement as to how it's best spent. Need for flexible budgets exist. Budget should be an objective, not a mandate that encourages dysfunctional behavior.

TRADITIONAL RETURN ON INVESTMENT COMPUTATIONS

Traditional return on investment decisions gave no credit for building up long-term strategic strengths and competencies. This often inhibits cooperative projects.

COMPARISON OF OLD AND NEW PRACTICES IN HANDLING MANUFACTURING BUSINESS RELATIONSHIPS

The procurement systems of many large public organizations have been built up over many years, with much accumulated experience. The systems are by now well-populated with regulations which ensure fairness to many bidders, prevention of possible fraud or malpractice, conformance with all of many government regulations, and ensure that these practices are known, and can be easily reviewed and proved to have been followed. These procurement practices developed under the influence of the concepts of mass production, when rapid response, customized production, and cooperation withcompetitors was not routine. For the world of agile manufacturing, they are impossibly slow, and inhibit, even prohibit, cooperation, customized production, flexibility and quick response. Existing procurement systems often deal with quality in out-of-date concepts, by specifying the manufacturing process in a way which forbids flexibility. The following pages compare a world class modern supplier or customer, with an old-style bureaucratic customer, and are presented in order to point out how important it is to deal with business systems, so that they not inhibit the move to agile manufacturing.

PROCUREMENT PRACTICES COMPARISON

WORLD-CLASS CUSTOMER	OLD-STYLE BUREAUCRATIC PRACTICE
• Control own policies • Can change to meet current business conditions	• Rigidly regulated

• Rules
  • Best commercial practice
  • Comply with laws, i.e. Environment, OSHA, EEC, Sherman Anti-Trust
  • Prudent, ethical, efficient
	• Rules dependent on product
	  • R&D
	  • Production
	  • Spares
	  • Services
	  • Construction

• Compete when it makes sense
  • Reduction in defects
  • Reduction in delinquencies
	• Full and open competition
	  • Maximum extent possible
	  • Every procurement

• Procurement Sensitivities
  • Customer value
  • Highest quality
  • Lowest cost
  • Market leadership
  • Highest market share
  • Return on assets
	• Procurement sensitivities
	  • Focused on prime contractor
	  • Socioeconomic goals
	  • Price versus quality
	  • Protectionism considerations
	  • Annual budgets
	  • Fraud and defective pricing

• Buys to flexible company specifications & standards or commercial specifications & standards	• Buys to government specifications & standards

• Long term agreements/relationships
  • Vendors/Suppliers
	• Annual contracts
	  • Primes/Subs

• Pricing
  • Standard accounting techniques from cost analysis and audit to price analysis
	• Pricing
	  • Compliance with rigid cost accounting standards

• Complete vendor involvement
  • Cradle to grave
  • Commodity teams
  • Sole source suppliers
  • Audits of quality, management
	• Micromanagement
	  • Audits
	  • Investigations
	  • Redundant testing
	  • Reports and data training and cost

• Full funding of programs	• Annual funding of programs
• Termination for cause	• Termination for convenience

WORLD-CLASS CUSTOMER	OLD-STYLE BUREAUCRATIC PRACTICE
GENERAL ENVIRONMENT	
• Serving these customers is viewed as highly desirable by suppliers and their employees. Companies seek entry.	• Companies withdrawing or seeking divestiture. Subtier suppliers dropping out. Increasingly viewed as less desirable customers by companies and employees.
• Business dealings are direct and focused on end results. Environment is positive and congruent with a productive, personally rewarding work ethic.	• Business dealings focus on complex processes. Environment is adversarial and bureaucratic.
• Free flow of information between buyer and seller -- barring competitive pricing information.	• Information flow generally more restricted.
• Relies on natural forces of competition to permit a simple system.	• Allows both increasing competition and complex regulation.
• Focuses attention almost exclusively on the present and future.	• Substantial resources devoted to past actions (e.g., after the fact audits and reviews).
• Requirements are tuned to the prevalent, non-adversarial and non-fraudulent case. Willing to take a low risk.	• Regulations seek to achieve a risk-free, but unattainable system. Regulatory presumption of wrongdoing imposes a "tax" on all procurement actions.
RELATIONSHIPS/PERSONNEL	
• Relationships are founded on trust, long-term relationships and faith in the industrial system.	• Relationships project a lack trust and a philosophy that industry is lacking in capability to manage itself. Sanctions are emphasized. Long-term relationships viewed as collusive and undesirable.
• Relies on integrity of the average American.	• Relies on regulations and processes written to eliminate / punish transgressions.
• Managed by seasoned professionals. Pay is commensurate.	• Tendency (mitigated by recent legislation) to short tenure assignment of non-procurement professionals. Pay is often inadequate.

WORLD-CLASS CUSTOMER	OLD-STYLE BUREAUCRATIC PRACTICE
PRODUCT DEFINITION	
• Requirements are clearly expressed and based on performance needs.	• Requirements definitions are overly complex and often state not only performance needs but mandate procedures and processes.
• Requirements tailored to individual program need. Suppliers' own systems are used to satisfy requirements.	• Many detailed requirements (how-to) apply to all procurements by policy rather than need. customer mandates the systems to be used.
CONTRACTING PROCESS	
• Contracts are in plain language and simple; i.e., based on UCC.	• Contracts are complex and voluminous to the point of irrationality.
• A deal is a deal. Agreements are final. Most audits are done in advance.	• Contracts are susceptible to repricing by audits as much as ten years after award.
• System viewed as flexible, responsive.	• System viewed as byzantine, rigid and non-responsive.
• Contract award system based on informed, "empowered" individuals.	• Award system based on detailed proposal paper promises and regulations.
• Award decisions tend not be questioned. When questioned, awarded work continues.	• Bid protests abound. To taking on trappings of court proceedings. "Stay" provisions apply to awarded work.

WORLD-CLASS CUSTOMER	OLD-STYLE BUREAUCRATIC PRACTICE
VALUE CONCEPTS	
• Prospective contractors earn the privilege of competing.	• Contractors feel entitled to compete for funds year after year.
• Acts as an informed purchaser of overall best value. Past performance is evaluated.	• Purchases tend to be on the basis of lowest price. Quality and past performance not often rated.
• Individuals are empowered to make award judgments. The system seeks to award to a supplier who will perform reliably.	• Decision-making authority of managers is diffused. The system seeks to award on low price promises despite doubts as to qualifications of a bidder or soundness of the price.
• Contract awards tend to be made to companies with continuous quality improvement.	• Existence of a quality improvement program is not even a consideration.
SANCTIONS	
• Transgressions result in punishment of individuals.	• Transgressions by individuals often result in punishment of entire organization.
• Transgressions by individuals are penalized without adding additional burdens on the system.	• Transgressions often cause permanent burdens to be added to the system.
• Legal status of private sector procurement people is the same as other citizens.	• Employees engaged in federal procurement are subject to more stringent legal sanctions than other citizens.

APPENDIX A

NEWS ITEMS FROM 1991

This section shows some press releases describing quick response industrial activities which exist today. Most were chosen because they illustrate how quick industrial response aided the war effort in the Gulf, illustrating the potential for the DoD. Note that in most cases quick response was obtained while coordinating work between several organizations, not just in one organization.

Shortened versions of some of the stories were used as boxed excerpts in Volume 1. They are repeated here in full, as originally published elsewhere, because the full publication contains many details of interest to people who work in manufacturing.

These stories show that quick response is technically possible today; however, it is not integrated into regular industrial or military organizations, and to succeed has to short cut the system. Today quick response is possible, but is the exception. In 2006 it will be the rule. Today it can be done, but logistic organizations are not set up to handle quick response in a routine way. In 2006 quick response will be pervasive and will be handled by daily routine.

ANTI-FRATRICIDE IDENTIFICATION DEVICE (AFID)

As preparations for the land war in Kuwait and Iraq began to heat up, a critical need surfaced for ways to identify friendly forces. At the request of the Director of the Joint Staff, Air Force Lt. Gen. M. P. C. Carns, DARPA undertook the job of sorting through the alternatives and recommending quick solutions that could help to avoid Allied casualties from friendly fire.

After exactly seven days of intensive brainstorming, design evaluation, rapid prototyping, three nights of ground testing, and three nights of flight tests involving Air Force aircraft and Army helicopters and ground vehicles, DARPA returned to General Carns with a series of recommendations.

One of the recommendations was to quickly finalize the design and begin production of a friendly forces identification beacon proposed by Test Systems Inc. of Hudson, New Hampshire. The design showed promise of being suitable for use on armored vehicles, relatively inexpensive, available quickly, and very effective.

At noon on Wednesday, February 13, General Carns directed DARPA to go ahead with the program. The following chain of events began immediately:

5:30 PM Wednesday

Test Systems was given authorization to proceed by DARPA

10:00 PM Friday

After seven prototyping cycles, the final electrical design was established and the mechanical configuration stabilized.

Midnight Saturday

A successful flight test was completed using a private aircraft and a breadboard version of the beacon located on top of an Army truck. The test was flown out of Moore Army Airfield at Ft. Devens, MA, and the ground site was set up in the nearby parachute drop zone.

1:25 PM Sunday

The mechanical design was finalized and fabrication of 10 production configured prototypes was begun.

8:00 PM Monday

Three prototypes were delivered to the Federal Express office at Manchester, NH. Serial Number 2 was headed for Riyadh, Saudi Arabia, and the other two (Serial Numbers 1 and 7) were on their way to Yuma, AZ, to be evaluated in an operational test run by Marine Air Test Squadron One, at MCAS Yuma.

By noon on Tuesday, six days to the minute from giving the go ahead, General Carns had a working prototype sitting on his desk, and a similar unit was on its way to Saudi Arabia by C-5 out of Charleston AFB, SC.

On Wednesday, Yuma testing concluded that a small change was required to make the beacon more acceptable to both the Army and the Air Force. TSI made the appropriate component changes in the electronics and production preparations continued.

Three days later, the Yuma tests concluded that the modified TSI beacon design was a preferred solution to the fratricide problem, and the first 40 production units were shipped by chartered airplane from Nashua, NH, to Dover AFB, DE, where they were transferred to a military aircraft for their flight to Saudi Arabia.

A total of 194 units were delivered before the war came to an end, 1800 were ready for assembly, and almost all of the parts for the full 10,000 were complete.

To accomplish this program, it was absolutely essential to use pre-existing industrial capacity and commercial parts - there was no time to develop a military-only capability. The aluminum was off-the-shelf 6061-T6; the printed wiring board was produced by a company that produces boards for both commercial and military projects, but this board had no Mil-Specs associated with it (the board design was completed on Sunday afternoon at about 4:00 PM and the first 1100 boards were back in Hudson, NH, on Tuesday, ready for component insertion and wave soldering). The critical components (the high power light emitting diodes) were commercial parts for which there is no equivalent military part - and it was in a plastic case (the government generally does not like to use plastic parts). The batteries were off-the-shelf Eveready Energizer alkaline C-cells made up into special 7-cell packs by a commercial battery supplier; the top window was cut from off-the-shelf Lexan sheet, and the base was machined from available stocks of Du Pont Delrin. Almost all of the electrical components were commercial parts. When you are in a hurry, you must use what is available, and the availability of commercial capability to meet an immediate need can be key to delivery of a useful military capability.

Genesis of a Bomb
TI's Role Critical In Quick Development of Weapon

by Gregg Jones
Staff Writer of The Dallas Morning News

For days, U.S. warplanes had pounded the Iraqi military bunker complex at Al Taji Air Base north of Baghdad without success. Even huge 2,000-pound bombs designed to slice through 6-foot-thick bunker walls could not breach the command lair, encased in concrete and buried 100 feet deep.

On the evening of Feb. 27, four days into the ground offensive against Iraq, a U.S. Air Force F-111F fighter-bomber streaked north across the Saudi desert on a course for Al Taji. A long, cylindrical device fell from the plane and guided by a laser, hurtled toward the bunkers. A small puff of smoke suddenly shot from an entrance to Taji Bunker No. 1. About seven seconds later, a huge explosion ripped through the command post, reducing the bunker to a jumble of broken steel and concrete, according to Air Force officials.

The mission marked the spectacular battlefield debut of the GBU-28, a bunker-killing bomb developed and rushed into combat with unprecedented speed by the Air Force, Texas Instruments, Inc., and Lockheed Missiles and Space Co. during the Persian Gulf war.

The GBU-28's psychological effect on Iraqi President Saddam Hussein and his military commanders - and the destruction of what Iraqi officials had thought to be an impregnable bunker complex - may never be known.

Coincidentally or not, a few hours after the destruction of the Al Taji command post, Iraqi officials indicated their readiness for a cease-fire.

"We'd like to take credit for ending the war, but in all honesty we don't know what role the GBU-28 played in Saddam Hussein's seeking a cease-fire," said Maj. Richard Wright, the GBU-28 program manager. "What I can tell you is the bunker facility had been hit by us previously and was still operating. I would suspect that (the GBU-28) got somebody's attention and that we had some effect on someone's ability to sleep at night."

The story of how the GBU-28 came into being, as pieced together from interviews with Air Force officers and Texas Instruments officials, offers a rare behind-the-scenes look at how home-front technology contributed to a overwhelmingly successful military campaign.

The bomb was the product of an extraordinary, seat-of-the-pants arrangement: No contract was signed; no written agreements were exchanged. Maj. Wright would later say that the Air Force in effect held out a credit card to TI and said, "Trust us."

Worst fears realized

The story begins last autumn, only weeks after the Aug. 2 invasion of Kuwait by Iraqi forces, when U.S. intelligence reports first raised concerns that existing bombs might be able to destroy heavily fortified enemy bunkers. Quietly, the Air Force launched design studies for a bomb that could penetrate the Iraqi underground fortifications.

When the air bombardment of Iraq began Jan. 17, the worst fears of U.S. military commanders were realized.

Air Force reconnaissance photographs showed that a number of Iraqi bunker complexes had withstood direct hits by bombs that could destroy typical concrete bunkers. The Iraqi command posts were either too deep or too well-protected by reinforced concrete.

Around Jan. 21, Air Force officials contacted aerospace companies across the country, asking for ideas on how to destroy the deep, hardened targets. One call went out to the Texas Instruments Defense Systems and Electronics Group in Dallas. The TI group had engineered laser-guided bombs capable of delivering with nearly pinpoint accuracy a 2,000-pound bomb that could punch through six feet of concrete.

In the meantime, Al Weimorts, an engineer at the Air-to-Surface Guided Weapons Systems Program Office at Eglin Air Force Base in Florida, began sketching designs for a longer, heavier bomb.

The plan quickly hit a snag. A key element to Mr. Weimorts' idea was to use off-the-shelf Air Force materials to construct the bomb. Otherwise, it would take months to develop and manufacture new bomb parts. The problem was finding a steel tube long and strong enough for the bomb body.

By luck or genius, the first of many strokes of fortune blessed the project.

A retired Army veteran at the Lockheed Missiles and Space Co. plant in Sunnyvale, Calif. - the company tapped by the Air Force to make the GBU-28 warhead - recalled that the Army stockpiled old gun barrels. The barrels happened to be made from the same hardened steel needed for the bomb body. The gun barrels were traced to the Letterkenney Arsenal in eastern Pennsylvania.

Without waiting for Pentagon approval, the Eglin weapons lab asked the arsenal to ship several 8-inch howitzer barrels to the Watervliet Army Arsenal in upstate New York. On Feb. 1, Army machinists started shaping the first bomb bodies from the gun barrels.

"We would have never been able to make it otherwise. If we had gone out to have somebody make them for us, it would have taken months," said Maj. Wright.

With one problem solved, a bigger obstacle loomed: The Air Force needed a guidance system that could deliver the high, unwieldy bomb to its target with pinpoint accuracy. The Air Force turned to Texas Instruments.

TI was asked to reassemble an engineering team that had helped design and build the Paveway laser-guided weapons, including penetrating bombs. On Feb. 12, Bob Peterson, the TI engineering manager for a previous penetrating-bomb project, flew to the Florida panhandle to meet with Air Force officials at Eglin Air Force Base.

Air Force engineers were still debating the merits of various bomb designs. TI was asked to stand by.

At this stage, it was clear that they wanted to do something in a hurry," said Dave Walp, a vice president in the TI Defense Systems and Electronics Group weapons systems unit. "We wanted very much to do what we could do to participate."

Playing a hunch, TI officials made preliminary arrangements with LTV Aerospace and Defense Co. to book time at the company's Dallas wind tunnel, critical to determining how to control a bomb. The only available time that met their narrow window of opportunity was the approaching weekend of Feb. 16-17.

Formidable challenges

On Feb. 14, just hours before the deadline to arrange the wind tunnel tests, an Air Force official gave the word: TI was to press full speed ahead to develop the sophisticated guidance kit for the new bomb.

Time was critical. TI engineers were being asked to deliver a stunningly complex guidance system with fine-tuned software in less than two weeks - work that under normal conditions would take many months.

The attitude was, let's cut through all the red tape and cut to the chase. Let's not sit around waiting for a contract to be signed. We'll figure out later how to get paid and when to get paid," said TI spokesman Tony Gelshauser.

TI engineers began furious preparations for the crucial wind tunnel tests. A detailed, one-fourth scale aluminum model of the bomb was crafted. From it, TI engineers had to learn everything about the bomb's aerodynamic characteristics to design software that could guide the bomb.

The length and weight of the bomb posed formidable challenges. For starters, the new bomb - at 4,700 pounds, twice the weight of existing penetrator bombs - would be far more difficult to control.

War demands necessitated that the TI team condense wind-tunnel and simulation tests - normally an 18-month to two-year process - into barely a week. At the same time, engineers were trying to calculate how different speeds and altitudes would affect the bomb. The odds of getting everything right in a matter of days were prohibitive, TI officials say.

"There was no margin for error at any place during this period," said Mr. Welp.

At the TI Dallas headquarters and the company's Lewisville defense plant, a team of up to 18 engineers wrestled with the numbing challenges, laboring under absolute secrecy. Workdays stretched into coffee-driven, 20-hour marathons.

On Saturday afternoon, Feb. 16, the wind-tunnel testing began under the scrutiny of five engineers - three from TI and a pair from the Air Force. The process was excruciatingly tedious. The bomb would be positioned and a rush of air would flow through the tunnel for 45 seconds. It would take 25 to 30 minutes to ready the wind tunnel for another 45-second blast of air.

From the results of these tests, the engineers had to determine the size and configuration of the bomb fins. Demands for precision were extraordinary - the slightest miscalculation could cause the bomb to tumble out of control the instant it was released from the aircraft. Typically, the engineers would have two months to fine-tune their calculations. Now, time was running out.

A few hours before the wind tunnel tests began, a New York Air National Guard C-130 transport had left Schenectady, N.Y., for Eglin Air Force Base with the first bomb body fashioned from a gun barrel.

In Dallas, the wind tests dragged on until after dawn on Sunday, Feb. 17. A few hours later, the engineers were back at it priming the wind tunnel, unleashing the blast of air for 45 seconds, scribbling calculations into their notebooks, then starting the process all over again.

When the tests ended early Monday morning, another set of TI engineers was waiting to plug the figures into a computer simulator. Throughout the week, the team tried one set of numbers after another. Gradually, they pinpointed the correct software parameters needed to guide the bomb.

On Feb. 19, the Air Force asked TI to prepare two bomb guidance units - the critical front and back portions of the bomb - as quickly as possible. TI officials warned the Air Force that the controlling software might need further adjustments. The Air Force wanted it regardless.

"We said, 'If you're willing to take the risk, we're willing to send them to you.' They said, 'Send it anyway,'" recalled Mr. Peterson.

Two days later, a TI Lear jet whizzed down the runway at Love Field with a pair of the bomb guidance units, bound for Eglin.

Meanwhile, TI engineers plowed ahead with final tests. With the ground war only hours away, the Air Force suddenly asked TI to rush two more guidance kits to Nellis Air Force Base in Nevada.

The TI team worked throughout the night Friday, Feb. 22, checking for software bugs. By 7 a.m. Saturday, the engineers were as satisfied as they were going to be; they had uncovered no bugs that would prevent the bomb from flying. After long days of frenetic work, the TI team began to feel cautiously optimistic.

Two more guidance kits were rushed to Love Field, and once again the TI Lear jet roared off with its precious cargo.

The next morning, an F-111 fighter-bomber dropped an inert GBU-28 onto the Tonopah Test Range; the bomb plowed more than 100 feet into the ground, exceeding even the most hopeful expectations of the project planners.

"We were thrilled," says Maj. Wright, who was anxiously awaiting the test results at Eglin.

'Euphoric exhaustion'

The secrecy surrounding the project prevented Air Force officials from formally notifying Texas Instruments of the test outcome. But company officials knew that the 9:30 a.m. Sunday call from the Air Force asking TI engineers to immediately prepare four additional bomb guidance kits for shipment could mean only one thing: The GBU-28 had worked.

The ground war was underway in Iraq when the four TI guidance kits and bomb tail sections arrived at Eglin on Monday, Feb. 25. The work of the TI team was over for the moment. "Euphoric exhaustion" swept through the ranks, recalled Mr. Peterson, the TI engineering manager.

For the TI crew, there was nothing to do but sit back and nervously await the bomb's debut.

On Tuesday, Feb. 26, the GBU-28 demonstrated its awesome destructive power in a test at Holloman Air Force Base in New Mexico. There, the bomb - 18 feet, 9 inches long - sliced through 10 huge slabs of concrete, together 22 feet thick. The Air Force reported that after passing through the concrete "like butter," the GBU-28 "skipped once on the ground and continued for about another half mile before it hit again."

The bomb had passed its tests. "But there was a lot of nervousness about whether it would work the next time," said Mr. Welp, the TI vice president. "We didn't know if it would work again when it really counted."

Hours before, an Eglin Air Force Base team had already poured more than 600 pounds of molten explosives into each of two GBU-28s. Filled with explosives, the bombs weighed 4,700 pounds each. They were still warm to the touch when Eglin personnel autographed the weapons and loaded them aboard a C-141 airlifter bound for Saudi Arabia.

Rumors were already circulating among U.S. airmen about the impending arrival of a huge new bomb. A curious crowd gathered as the two GBU-28s were fitted to the undersides of a pair of F-111s, only hours after arriving in Saudi Arabia on Feb. 27. Loading was delayed while airmen covered the bombs with defiant graffiti.

Within five hours, the F-111s were en route to Al Taji Air Base - and a successful strike on the Iraqi bunker, according to Air Force officials.

A few hours later, the war was over.

Days passed before the TI engineers who played a key role in bringing the bomb to fruition learned that the GBU-28 had worked to perfection.

"When the war ended, we didn't know if it was all for naught," said Mr. Welp.

"The Air force did an excellent job of keeping the program moving," said Mr. Peterson. "There was never any doubt as to what we were supposed to be doing."

The Air Force is pressing ahead with plans to develop rock-propelled bombs that will even more effectively destroy bunkers and other heavily fortified command structures. Those involved say the work is made easier by memories of the wartime triumph.

"This was a once-in-a-lifetime deal. No days off, but everyone that was a part of the program was absolutely ecstatic about it," said Maj. Wright. "We accomplished in a month what normally takes 2-1/2 years to do. We had a tremendous team of both government and contracting experts, and we were able to do this job without having anyone breathing down our necks. We're just now sorting out payments (to Texas Instruments and Lockheed) and things like that.

He laughs at the audacity of it all.

"Everyone had a common goal: to build the biggest, best bomb we could build. It was great."

Rapid Design and Production of a Fan Shroud For the CH-47D Chinook Helicopter

During the Gulf crisis Boeing Helicopters were notified of a problem on the CH-47D Chinook helicopter on October 1, 1990. A new shroud was designed and approved by October 11 and delivery of new sets of shroud commenced on October 29, 1990.

This highly responsive effort by Boeing solved a problem experienced by CH-47D Chinook helicopters in Saudi Arabia and enabled those aircraft to provide support for Desert Shield. Intense ambient temperatures caused the existing forward transmission cooling fan shroud to collapse and score the forward sync shaft.

The first warning of this condition to Boeing Helicopters was on October 1, 1990. Subsequent testing at Boeing Helicopters was conducted on the existing shroud to investigate the failure mode. The problem was caused by the material used to form the segmented shells of the shroud, and a recommendation was made on October 4 to replace the thermoplastic material with fiberglass. The fiberglass material was chosen because of the application and the availability at Boeing Helicopters.

The Boeing Helicopters Operations Developmental Support organization was assigned to produce 110 shipsets of spares kits for replacement on aircraft fielded in Saudi Arabia. This responsibility included tool design and fabrication, sheetmetal and composite fabrication, and assembly. This effort took place in one building and was made possible by intense use of computers in the process. The graphite tooling was designed without a back-up structure, a step which reduced tool fabrication flow time. In addition, more flow time was eliminated by curing the tools in an oven for 12 hours as opposed to a normal room temperature cure of three days. Initial tooling was ready on October 8 and the first shroud assembly was completed on October 10. A trial installation was performed on October 11 for representatives of the Army Aviation Systems Command. With immediate approval of the redesigned shroud, rate tooling was fabricated which allowed a production rate of 20 shipsets per week to be reached by the following week.

The volume of shrouds produced was out of norm for a facility that specializes in prototype work. The skills and equipment located in one building were keys to successfully meeting an immediate requirement. An enthusiastic, motivated workforce performed in a concerted manner to keep the troops supplied. This team effort, which one line supervisor described as patriotism, enabled Boeing Helicopters to deliver 75 percent of the shipsets by December 7 and all of the shipsets by December 21. All shroud retrofit kits were built and delivered at company risk prior to contract award.

The Motorola Pager

Motorola has employed a radical new manufacturing approach involving robots, the first step towards a grand plan for all its operations.

From the outside it looks like an ordinary factory. But tucked inside along one wall of this Motorola, Inc. plant in southern Florida is a glimpse of the future of manufacturing.

Dubbed Operation Bandit because it borrows innovations from dozens of other manufacturers, the minifactory can build a sophisticated pocket pager only two hours after receiving the order. In the surrounding factory, where Motorola uses conventional methods to build similar pagers, it would take nearly a month to collect all the necessary components to fill the same order.

Here in the Boynton Beach facility, robots vastly out number humans. These steel-collar workers get their production orders electronically from Motorola headquarters in Schaumburg, Illinois. Then they perform all the assembly, adjusting, and checking without human intervention. And they do it in one hundredth of the time and with half as many defects as ordinary manufacturing methods.

Only a dozen attendants are needed to monitor the Bandit system and load it with enough parts to run automatically for eight hours at a time. The project, says Christopher Galvin, Motorola's senior vice-president and chief corporate officer, is "an experiment to let people rewrite the rules".

Motorola's Paging Division launched the $US9 million operation in mid-1986 as a survival tactic. The company still dominates the U.S. market and boasts 7 million pagers in service and a 20 percent annual growth in sales. But Japanese producers have forced out half a dozen other domestic makers in the last decade, mainly by cutting manufacturing costs each year. To stay competitive, Motorola decided it needed a radical new approach.

The new factory certainly fills the bill. It is set up to produce only one type of pager, the popular "Bravo" model Motorola introduced in 1987. The pager retails for about $US220 and is marketed under several brands. Since each of the receivers, no larger than a box of matches, works on a unique combination of access code and radio frequency, the facility can build a staggering 29 million variations.

By 1990 it is expected to handle about 40 percent of Motorola's total output of the Bravo pager.

The process starts with field orders sent to Schaumburg by sales staffers armed with Macintosh computers. Those orders are entered in mainframe computers and routed to Boynton Beach, where 27 small robots -- some performing up to six tasks -- build the beepers, adjust their electronics, and affix proper labels and serial numbers. Local computers control the movements of each robot.

When Bandit receives an order, it assigns each unit to be built to a small, coded steel pallet. The pallet carries a circuit board upon which robots assemble about 130 electronic elements -- some as tiny as one and a half square millimeters. Later, the completed innards are transferred to a larger pallet for final assembly with the beeper case and control buttons. Mechanical vision systems check the robots' work at several stages, and key components are 100 percent pre-tested along the way.

It could take a company years to plot such a radically new approach: Motorola's Paging Division gave itself just 18 months. Motorola also decided that virtually all the system design, right down to specifying which "fingers" the robots use in assembly, should be handled by a two-member team of the company's own designer-engineers.

The group, armed with an inch-thick "contract book" of performance goals, soon realized it had no chance of developing all the necessary technology in time. But it didn't have to. Motorola had already surveyed several industries to establish world-class performance benchmarks; the car industry for material handling, for example, and the pocket calculator industry for speedy product development. The team simply copied those approaches when possible. Thus it could concentrate its development efforts only where new technology was truly needed.

"We had no choice," says Scott Shamlin, director of manufacturing operations for the paging division.

The Bandit team redesigned the insides of the Bravo pager to make robot assembly and adjustment easier. It also set up a new cost-accounting method that tracks overheads mainly as a function of production-cycle times and the marketing group's ability to fill the factory with orders. "You can streamline the traditional system to get maybe a 20 percent improvement," says Motorola's Galvin, "but to get orders of magnitude of change you have to rethink the whole system."

How is Bandit working out? Tightlipped Motorola officials say it is too early to tell, since the line began operating only last February. But Merle Gilmore, vice-president and general manager of the Paging Division, boasts that costs are already comparable to much less sophisticated methods and are falling. Galvin predicts it could take three years just to learn how to run the automation at peak efficiency, though he says that the company expects to recoup its investment within two years.

APPENDIX B

PROGRESS OF TECHNOLOGY

CHANGE IN THE METAL FABRICATION INDUSTRY

R. Jaikumar, ["From Filing and Fitting to Flexible Manufacturing: A Study in the Evolution of Process Control", Harvard Business School, 1988] traced the history of manufacturing epochs in the metal fabrication industry, in particular, the small arms manufacturing industry.

The evolution he traces is applicable to a wide range of manufacturing industry. The table provides useful data, showing how manufacturing is developing by natural evolution into the age of the agile enterprise.

Jaikumar's table is reproduced here with a column added for the agile manufacturing era.

	English System 1800-1850	American System 1850-1900	Taylor Scientific Management 1900-1950	Dynamic World 1950-	NC Era 1970-	Computer Integrated Mfg. 1980-	**Agile Enterprise 2000-**
Number of Machines	3	50	150	150	50	30	**Count systems not machines**
Minimum Efficient Scale (Number of People)	40	150	300	300	100	30	**Count people on team**
Staff/Line Ratio	0:40	20:130	60:240	100:200	50:50	20:10	**40:10 ?**
Productivity Increase Over Previous Epoch	4:1	3:1	3:1	3:2	3:1	3:1	**3:1 ?**
Rework as Fraction of Total Work	.8	.5	.25	.08	.02	.005	**.002 ?**
Engineering Ethos	Mechanical	Manufacturing	Industrial	Quality	Systems	Knowledge	**Systems Understanding**
Process Focus	Accuracy	Repeatability	Reproducibility	Stability	Adaptability	Versatility	**Agility**

Table Continued on Following Page

	English System 1800-1850	American System 1850-1900	Taylor Scientific Management 1900-1950	Dynamic World 1950-	NC Era 1970-	Computer Integrated Mfg. 1980-	**Agile Enterprise 2000-**
Focus of Control	Product Functionality	Product Conformance	Process Conformance	Process Capability	Product/ Process Integration	Process Intelligence	**Systems Intelligence**
Instrument of Control	Micrometer	Go/No-go Gauges	Stop Watch	Control Chart	Electronic Gauges	Professional Workstation	**Network**
Organizational Control	Break-up of Guilds	Staff/Line Separation	Functional Specialization	Problem Solving Teams	Cellular Control	Product Process Program	**Distributed System Coordination**
Standards for Work	Absolute Standards on Products	Relative Standards on Products	Work Standards	Process Standards	Functional Standards	Technology Standards	**Interface Standards**
Work Ethos	"Perfection"	"Satisfice"	"Reproduce"	"Monitor"	"Control"	"Develop"	**"Entrepreneur"**
Skills Required	Mechanical Craft	Repetitive	Repetitive	Diagnostic	Experimental	Learning Generalizing Abstracting	**Implement on a Network**
Control of Work	Inspection of Work	Tight Supervision of Work	Loose Supervision of Work/Tight Supervision of Contingencies	Loose Supervision of Contingencies	No Supervision of Work	No Supervision of Work	**Focus is now on Market. Quality Implicit**

APPENDIX C

RANKING OF U.S. IN RELEVANT SCIENCE AND TECHNOLOGY CATEGORIES

From "World Competitiveness Report 1991",
The World Economic Forum,
Geneva, Switzerland

Note: The U.S. ranks around 4 in most items, but is 10 in cooperation between companies in R&D.

Figures are for 1989

(s) indicates data based on survey of opinions, not statistical data

% of total R&D by business	Switzerland	ranked 1
	Belgium/Lux.	ranked 2
	Germany	ranked 3
	USA	ranked 4
Real growth in business R&D expenditure	USA	ranked 16
% of government R&D allocated to non-defense research	USA	ranked 21
% of R&D personnel in industry	Switzerland	ranked 1
	Germany	
	Sweden	
	United Kingdom	
	Austria	
	USA	ranked 6

% university graduate scientists and engineers in industry	USA	ranked 1
Patents per million inhabitants	Switzerland Canada Belgium/Lux. Netherlands USA	ranked 1 ranked 5
Annual compound % change between patents secured overseas and domestic patents granted to non-residents	USA ranked 17 (patent balance very negative)	
(s) Effectiveness of intellectual property legislation	Japan Switzerland Germany USA	ranked 1 ranked 4
(s) Ability of companies to seek out and exploit new technology and processes worldwide	Japan Switzerland West Germany USA	ranked 1 ranked 4
(s) Level of cooperation between enterprises	Japan Germany Switzerland Sweden Netherlands France Finland Belgium/Lux. Denmark USA	ranked 1 ranked 10
(s) Effectiveness of basic research in meeting long term needs of economy	Germany Japan Switzerland USA	ranked 1 ranked 4
(s) Access business has to university R&D programs	USA	ranked 1

APPENDIX D

Task Description

The defense authorization bill for 1991 directed the Secretary of Defense to submit to Congress a National Defense Manufacturing Plan. Accordingly, Undersecretary of Defense Donald J. Yockey appointed a broad-based government agency task force to prepare such a plan. In addition, the Iacocca Institute at Lehigh University was asked by the Office of the Secretary of Defense (OSD) MANTECH program office to organize an industry-led response to the Congressional directive.

The focus of the project was the direction in which advanced manufacturing was moving today and the opportunity this presented for U.S. industry if a concerted effort were made to exploit that opportunity. The parameters of the project, were:

- That the vision drawn of manufacturing in fifteen years be drawn from the many excellent reports recently published and reflect a consensus of a broad spectrum of experts, not the predictions of the project members;
- That the vision address the infrastructure of manufacturing in 2006, as well as the subsystems required to support the infrastructure, but not the underlying manufacturing process technologies.

The 21st Century Manufacturing Enterprise Strategy project was led by industry in coordination with the Department of Defense. The expenses of the industry participants, including salaries and all travel and living expenses over a period of three months, were paid by industry. This represents a major commitment on the part of 13 corporations who contributed manufacturing executives to the project's inner core. In addition, executives from over 100 additional companies participated, at company expense, in two rounds of interaction with the ongoing work of the inner core. The responses of these participants materially influenced the outcome of the project.

The Iacocca Institute's approach to this project was to create a three-tiered executive vehicle. The first tier was an inner core team of high-level manufacturing executives, together with Department of Defense representatives, who over a period of five and one-half months would meet in intense sessions at Lehigh University and who were supported by university faculty, staff and researchers.

The second tier was an advisory core, a group of experts in various fields of manufacturing technology, vision creation, and cooperation mechanisms among industry partners, who would address these and other critical issues.

Lastly there would be an outer core of high-level industry executives with whom the preliminary draft of the inner and advisory core's sessions would be shared for review and feedback in an executive briefing/mini-workshop format. Following these workshops, the preliminary draft would then be revised and edited, and once again presented to the outer core for further review.

The Approach:

- The Iacocca Institute of Lehigh University would facilitate pursuit of the vision, provide leadership, and coordinate the activities of various core members, as well as provide research capability and staff support.
- The inner core team, listed below, would consist of manufacturing executives whose task it would be to formulate a structured vision and enterprise strategy and to recommend a continuation mechanism to implement that strategy.
- The project strategy was to start with existing visions and other documents to gain the benefit of prior work, and in order to reach rapid consensus among inner core team members on the vision advanced.

- Hundreds of reports and source documents were screened by the research staff to provide the inner core with the most current and insightful reading material. Twelve examples are listed under "Selected resources studied by the Inner Core" on the following pages.
- The inner core would use an advisory core, again listed, of selected executives as subject matter experts for briefings as required.
- The inner core team would share its preliminary plans with industry executives and involve this broader outer core of executives, listed by organization, in executive briefings/mini-workshops to provide critical review and feedback during the task.
- The inner core team would then adopt where appropriate, or reply to, the outer core critique in order to provide both the sense and the fact of participation and ownership of the vision to outer core members.
- Acting in concert with inner core team members as well as other participants in the project, project team members would then work to obtain CEO endorsement of the vision and framework, as well as commitment, to maintain the momentum.

Differences from prior approaches:

- Project led by industry.
- The vision and other activities were centered around searching out the best reports and forming a convergent view, rather than "starting over."
- This project is action oriented. A primary focus is on securing a corporate buy-in at the highest levels of industry to the vision and to the concept of cooperation in carrying out the recommendations.
- A continuation mechanism is defined: see the Agile Manufacturing Forum described in the previous chapter.

Advisory Core subject matter experts:

- Steven V. Balint, Assistant Deputy Chief of Staff for Weapons Systems Production Management, U. S. Army
- Steve Bomba, Vice President, Technology, Johnson Controls
- David W. Cheney, Senior Associate, Council on Competitiveness
- Philip Francis, Vice President, Corporate Technology Center, Square D
- Robert W. Hall, Editor-in-Chief, Target
- Richard H. F. Jackson, Deputy Director, Manufacturing Engineering Laboratory, National Institute of Standards and Technology
- Ben Kaminski, President, CAM - I
- Michael J. Kelly, Director, Defense Manufacturing Office, Defense Advanced Research Projects Agency
- Charles Kimzey, Assistant for Manufacturing Technology, Office of the Secretary of Defense
- George Kuper, President, Industrial Technology Institute
- David Lando, Vice President, AT&T
- Mark S. Lang, Executive Director, Ben Franklin Advanced Technology Center
- Peter W. Likins, President, Lehigh University
- Steven M. Linder, Director of Production Assessment Division, Office of the Assistant Secretary of the Navy
- James Ling, President, Ling Technologies, Inc.
- Thomas Mahoney, Acting Executive Director, Manufacturing Studies Board
- Lt. Col. Erik Mettala, Program Manager, Defense Advanced Research Projects Agency
- William S. Safier, Director, Naval Industrial Resources Support Activity, United States Navy
- Charles L. Strecker, Manufacturing Technology Directorate, Electronics Division, Wright Laboratory, United States Air Force
- Barry Whalen, Vice President, MCC

Representative resources studied by the Inner Core:

- "Can Small Business Help Countries Compete?" (Howard) **Harvard Business Review** Nov/Dec '90
- Department of Defense Critical Technologies Plan, 1991.
- "Does Corporate Nationality Matter" (Reich) **Issues in Science and Technology** Winter '90-'91
- "Future Factory System Formulated in Japan (2)"(Suda) **Techno Japan, Vol. 22(10),** October 1989.
- **Gaining New Ground: Technology Priorities for America's Future,** Council on Competitiveness, 1991
- **Integrating Commercial and Military Technologies for National Strength: An Agenda for Change (Van Opstal)** Report of the CSIS Steering Committee On Security and Technology.
- **Manufacturing 21 Report - the Future of Japanese Manufacturing,** Association for Manufacturing Excellence, 1991.
- **Report of the National Critical Technologies Panel,** National Critical Technologies Panel, 1991

- "Strategic Intent" (Hamel & Prahalad) **Harvard Business Review** May/June '89
- **U.S. Defense Industry - Key Issues for the 1990s**
- "Who Is Them" (Reich) **Harvard Business Review** Mar/Apr '90
- "Who Is Us" (Reich) **Harvard Business Review** Jan/Feb '90

Selected Advisory Core Topics:

- Air Force Microelectronics Manufacturing Science and Technology (MMST)
- ATP Program as Mechanism
- Business of Paradigms, The: Discovering the Future (video tape)
- Council on Competitiveness Report, Gaining New Ground: Technology Priorities for America's Future:
- Defense Advanced Research Projects Agency: Manufacturing and Design Engineering in Ultra Reliable Systems Acquisition for Devices on Demand; and "Micro Tech 2000".
- Department of Defense MANTECH Program
- IMS as a Possible Framework Model
- ITI Experience with Mechanisms
- LINC as a Concept for a Mechanism
- Manufacturing Studies Board Reports
- Manufacturing 21 Report
- MCC as a Mechanism
- NCMS as a Mechanism
- Power of Vision, The: Discovering the Future (video tape)
- U. S. Memories as a Case Study
- White House Office of Scientific and Technology Programs Critical Technologies Report

Outer Core organizations who hosted workshop briefings:

- Aerospace Industries Association
- Computer Aided Manufacturing-International (CAM-I)
- Council on Competitiveness
- Defense Science Board Summer Program
- Electronics Industries Association
- Industrial Research Institute, Inc.
- IC^2 - Innovation, Creativity, Capital
- Microelectronics and Computer Technology Corporation
- National Machine Tool Builders Association
- National Academy of Engineering
- National Center for Manufacturing Science
- National Institute of Standards and Technology
- National Security Industrial Association

Outer Core organizations represented at workshops:

- Allen-Bradley
- Allied Signal Aerospace
- Aluminum Company of America
- Applied Materials
- Babcock & Wilcox
- Bethlehem Steel
- Bodine Corporation
- Boeing Computer Services
- Bridgeport Machines Inc.
- Brown & Sharpe Manufacturing Company
- Burdeshaw Associates, Lt.
- CAM-I, Inc.
- Carnahan & Associates
- Carnegie Mellon University
- Carnegie Institute of Technology
- Carpenter Technology Corporation
- Cincinnati Milacron
- Citibank
- CompuAdd
- Council For Equal Business Opportunity, Inc.
- David Taylor Research Center
- David Sarnoff Research Center
- Digital Equipment Corporation
- Englehard Corporation
- Enterprise Integration Technologies
- Extrude Hone
- Factorial Systems, Inc.
- Ford Motor Company
- General Motors Technical Center
- General Electric
- General Dynamics
- Georgia Institute of Technology
- Giddings & Lewis, Inc.
- Grumman Aircraft Systems/Product Operations
- Hewlett Packard Company
- Honeywell Corp.
- Howmet Corporation
- Hughes
- Hughes Aircraft
- Institute for Applied Composites Technology
- Johnson & Johnson
- Lanxide Corp.
- Litton-Airtron
- Lockheed Missiles & Space Company, Inc.
- Lockheed Corporation
- Loctite Corporation
- LTV Aircraft Products Group
- Martin Marietta Corporation
- Martin Marietta Energy Systems, Inc.
- Masco Machine, Incorporated
- Meridian Corporation

- Mechanical Technology Inc.
- Microelectronics & Computer Technology Corporation
- Moore Special Tool Co., Inc.
- National Steel & Shipbuilding Co.
- Pennsylvania State University
- Protein Technologies International
- Purdue University
- S.E. Huffman, Corp.
- Sandia National Laboratories
- Sematech
- Sherwin-Williams Company
- Society of Manufacturing Engineers
- SofTech, Inc.
- South Carolina Research Authority
- Strategic Insight
- Sverdrop Technology
- Teledyne Brown Engineering
- Ten X Technology, Inc.
- Texas Instruments
- Textron Lycoming
- Timken Company
- United Technologies
- University of Miami/Department of Industrial Engineering
- Vindicator
- Xerox Corporation
- Xerox Advanced Information Technology

APPENDIX E

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Volume 1 describes a non-technical vision of agile manufacturing as a system in which technologies, management structures, and social values are synthesized into a powerful competitive weapon.