ADVANCED SYSTEMS FOR MANUFACTURING

12th Conference on Production Research & Technology

Conference Proceedings

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PREFACE

These proceedings document the presentations made at the 1985 Manufacturing Systems Research Conference, the 12th in a series of conferences on production research and technology, this one held at the University of Wisconsin—Madison, May 14-17, 1985. The papers have been prepared by the grant-recipients of the National Science Foundation's program in Production Research and Technology and are concerned with research in the field of manufacturing engineering and management. It is hoped that these research reports will be of particular interest to production engineers, research managers, and university faculty engaged in the various areas of manufacturing systems research.

The papers in this proceedings have been grouped to correspond to their order of representation at the conference. There are three broad groupings for the 13 conference sessions: manufacturing processes, management of manufacturing, and new manufacturing technologies. In the manufacturing processes area, there are five sections covering a wide range of different processes including cutting, forming and casting. There are three sections on issues related to manufacturing management while the manufacturing technologies area contains five sections on assembly, controls, sensors, software, and vision.

This conference and proceedings come at a time when government, industry and academia are recognizing the importance of the integration of the many elements and facets of manufacturing. The past several decades have witnessed a dramatic increase in the availability of technologies capable of increasing manufacturing productivity and meeting the world's need for manufactured products.

Industry is seeking educated personnel and basic research to aid in establishing solid technological frameworks for manufacturing upon which can be based future developments and growth. Universities, national laboratories, independent institutes and small businesses are responding as never before to the manufacturing community. University/industry relationships are emerging and the relationships reflect more formalized commitments, designed to have both breadth and depth of involvement. New academic degree programs in manufacturing systems engineering are emerging to produce engineers who can assist industry in absorbing and implementing modern technology. The National Science Foundation, other government agencies, and professional societies such as the Society of Manufacturing Engineers are serving as important catalysts to increase the focus of industry and academe on manufacturing issues and solutions.

It has been a privilege to work with Dr. William M. Spurgeon of the National Science Foundation and to host this 1985 conference at the University of Wisconsin—Madison. We acknowledge with thanks the staff of the Society of Manufacturing Engineers for its cooperation in producing this bound volume. Particular thanks go to Sue Genske who served as the Conference Secretary and Administrator.

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TABLE OF CONTENTS

Opening Remarks

Session I: Controls

Session II: Management of Manufacturing I

Session III: Management of Manufacturing II

Session IV: Management of Manufacturing III

Session V: Assembly

Session VI: Manufacturing Processes I

Session VII: Manufacturing Processes II

Session VIII: Manufacturing Processes III

Session IX: Manufacturing Processes IV

Session X: Sensors

Session XI: Manufacturing Processes V

Session XII: Vision

Session XIII: Software

Opening Remarks

Computer Integration of Engineering Design and Production: A National Opportunity

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ABSTRACT. This work is a summary, with further observations, of a report published by the Manufacturing Studies Board of the National Research Council. That report is the work of a committee of which the author was chairman. The Manufacturing Studies Board carries out research for various government agencies, including the National Science Foundation. The work supported herein was funded by the National Aeronautics and Space Administration but is significant to the NSF Grantees.

The NASA undertakes large, complex technical efforts in research, development and production of spacecraft and space systems. Major efforts, such as the upcoming Manned Space Station, require extensive interchange of computer based data between design and production. The investigation was based on case studies of five companies and led to identification and recommendations in data management requirements in integrated design and production and to correct deficiencies in current efforts of interaction.

INTRODUCTION. The most critical problem faced by too many U.S. Industrial executives today is the steady decline in their companies' competitiveness at home and abroad, and the resultant loss in market share. A major reason for the decline has been the gradual emergence of a technology gap in mannufacturing. It has not been a single identifiable event, but a slow erosion of the technological foundation of manufacturing. The keys to regaining competitiveness in most U.S. manufacturing industries are quality, productivity, and responsiveness in bringing new products to the marketplace. A primary technology for attaining these attributes, across industries, is computer-integrated manufacturing.

Manufacturing includes all activities from the perception of a need for a product, through the conception, design, and development of the product, production, marketing, and support of the product in use. Every action involved in these activities use data, whether textual, graphic, or numeric. The computer, today's prime tool for manipulating and using data, offers the very real possibility of integrating the now often fragmented operations and manufacturing into a single, smoothly operating system. This approach is generally termed computer-integrated manufacturing (CIM).

Computer-integrated manufacturing can be employed at many levels short of total integration, which in fact has not yet been achieved anywhere. Manufacturers who are leaders in CIM typically have concentrated their efforts in two areas:

- computer-aided design (CAD), which applies the computer to the creation, modification, and evaluation of product design, and
- computer-aided manufacturing (CAM), which applies the computer to the planning, control, and operation of a production facility.

Manufacturers that concentrated on CAD and CAM in the early stages of the technology's application generally paid little attention to the interface between the two. In most companies, the activities were in different departments with heterogeneous computers and languages, inconsistent objectives, and little or no consideration given to the transfer of information between the two in either direction. Results have often been "islands of excellence" separated by poor performance, adversarial relationships and isolated measures of performance. What is really important is how the entire system of manufacturing performs.

In bringing this report before the National Science Foundation Grantees Conference emphasis will be on the role of technology and the goals of NASA in funding the study by the NRC. Two goals of NASA are to 1) launch a manned space station in 1992 with a program budget of $8 billion, 2)"to be a leader in development and application of advanced technology and management practices which contribute to a significant increase in Agency and National Productivity".

BENEFITS. In responding to the charge, the Committee visited five companies that have been leaders in implementing computer-integrated manufacturing and studied three major government programs in this field. The companies are Deere and Co., McDonnell Aircraft, General Motors, Westinghouse Defense and Electronic Center, and Ingersoll Milling Machine Co. Outside of this study companies as small as $15 million annual business are performing equally well. It became clear that the problem is much broader than the CAD/CAM interface. Information is used in manufacturing from the conception of a product to its delivery and use in the field. Leaders in U.S. manufacturing have already realized substantial benefits from the computer, but the potential benefits of computer integration may be much greater. One of the best documented examples of the benefits of integrating information is Boeing's experience with its most recent airplane programs, the 757 and 767. The company realized significant improvements in design and production, reduction of shortages, adherence to schedules, and budgetary performance in comparison with earlier airplane programs.

Other examples of excellence in design, reduced work in process, lead-time reduction, and improved productivity and quality were observed in all the firms interviewed by the Committee. In one, for example, the adoption of CIM led to a reduction in the time from release of the design to assembly from 18 weeks to 4 weeks, and inventory was reduced from three month's supply to one month. These improvements were due in large part to integrated data handling, often manual, from start to finish of the manufacturing process. The values shown below are representative of the intermediate benefits of 10-to-20-year efforts. Further benefits are expected to accrue as full integration is approached.

Benefits Achieved

Reduction in engineering design cost	15-30%
Reduction in overall lead time	30-60%
Increase product quality as measured by yield of acceptable product	2-5 times previous level
Increased capability of engineers as measured by extent and depth of analysis in same or less time than previously needed	3-35 times
Increased productivity of production operations (complete assemblies)	40-70%
Increased productivity of (operating time) capital equipment	2-3 times
Reduction of work in process	30-60%
Reduction of personnel costs	5-20%

The challenge of manufacturing management is broadening from the historic interest in handling and processing materials to include the management of information that controls those processes. This major substantive shift is the result of marketplace pressures, which demand greater manufacturing flexibility, improved quality and performance, and faster delivery. Factory operations have always been driven by marketplace needs. Unlike the past, however, the market pressures that necessitate computer-integrated manufacturing are not directly related to the technology. The computer integration of factory data allows higher quality, shorter cycle time between design and production, efficient production of small batches, and faster incorporation of design changes--which in turn respond to the market demand for flexibility, quality, and delivery.

MANUFACTURING, COMPUTERS, AND INTEGRATION. Even before the turn of the century, companies progressively divided manufacturing activities into their basic elements and developed specialized equipment and labor to handle them efficiently. The result has been large increases in output and quality, relative to cost. At the same time, this division has so fragmented the functions of manufacturing that beneficial interactions have been lost. As a result of the fragmentation and the difficulty of visualizing the system as a whole, most efforts to increase the cost-effectiveness of manufacturing have been directed at optimizing its bits and pieces independently resulting in far from optimal performance of the system. Manufacturing support costs, usually referred to as indirect costs, have grown to far exceed the direct labor costs that receive so much attention from management. In effect we are devoting most of our attention to the wrong problems.

Computers offer the possibility of reintegrating these fragmented functions into a single, smoothly operating manufacturing system with reduced total manufacturing costs, reduced lead time and improved quality. Computer-integrated manufacturing (CIM) in a manufacturing enterprise occurs when:

- all the processing functions and related managerial functions are expressed in the form of data,
- these data are in a form that may be generated, transformed, used, moved, and stored by computer technology, and
- these data move freely between functions in the system throughout the life of the product,

with the objective that the enterprise as a whole has the information needed to operate at maximum effectiveness.

Of the countless interactions required in a fully integrated manufacturing system, the interface between engineering design and production--that is, between CAD and CAM--is a major stumbling block in achieving computer integration. In the movement of a product from initial concept to finished form, the organizational division between engineering design and production has been, until very recently, the most clear-cut and accepted. As a result, efforts to brdige this interface have lagged progress in the computer intergration of applications with those areas.

THE POTENTIAL OF COMPUTER-INTEGRATED MANUFACTURING. The computer can provide manufacturing with two powerful, never-before-available capabilities:

- flexible, data-driven automation--for example, the choice of a DNC program as a function of the part processing plan.
- on-line decision-making algorithms--the ability to determine at any time the system status and immediately generate alternatives, and choose the best one, based on selected criteria.

The computer has the potential to provide these capabilities not only for limited portions of manufacturing activity, but for the entire manufacturing system. This use of the computer is producing what is being called the computer-integrated manufacturing system, portrayed generally in Figure 1.

In today's manufacturing environment in the United States, both managers and engineers often treat manufacturing as a unidirectional system in which data and information flow only downstream from product design to production to shipping. Realization of the potential offered by CIM requires a data handling system that assures free access to data (though limited access to change the data) and the flow of data among all parts of a manufacturing system.

Information in a CIM system is extracted from fully automated segments of a process for use in controlling, planning, or modifying input into the process. Thus, a system having an objective and a means of detecting deviations from that objective can take corrective action to decrease the deviation.

Information from segments that depend wholly or partially on human judgment is made completely available to the user, and computer facilities for simulation and prediction are available. This is neither feed-forward nor feed-back control but concurrent perception of all factors entering a decision.

The path in Figure 1 labeled "cost and capabilities" is directed at improving cost-effectiveness by enabling both design and manufacturing engineers to evaluate the consequences of each alternative design concept and each decision on production methods. The "performance" path will incorporate quality control in the system.

APPROACHES TO COMPUTER-INTEGRATED MANUFACTURING. Each company studied viewed its business from both global and domestic perspectives and considered integration technology a primary need for supporting its business strategy. All cited competition from foreign nations and a need to improve responsiveness to meet worldwide demand as a major strategic issue and incentive for CIM. One company noted that it was continually forced to improve on its own technology, which was being exported through offshore sales and through offset agreements that require production of parts and assmeblies by foreign manufacturers. Demand for quality and responsiveness in the U.S. marketplace was another incentive. Each of these leading companies introduced computer integration only after serious consideration of the resources required, the risks, and the expected benefits.

The efforts of these companies focused on improving the information flow within the factory and particularly between the engineering design and production functions. The managers interviewed remain unsatisfied with the adequacy and timeliness of the information flow and believe that improvemnt in data communication will further improve corporate productivity and product quality.

MANAGEMENT COMMITMENT TO CIM. The direct involvement of top management was found to be the key to successful CIM programs in the companies visited. At one company, for example, systems designers were spending 60 percent of their time reconciling data bases, and action by the chief executive officer was necessary to bring about change. He initiated a review of the data structure and data access needs and ordered a halt to new computerization during the two years necessary to create a new, unified data base. At another company, insufficient visibility of top management support caused the CIM effort to flounder. With the creation of an executive vice presidency for technology, the company regained focus and direct involvement of top management in CIM.

Companies take diverse approaches to CIM. Most of those visited started with narrow applications and gradually linked them to broaden the integration effort. The one company that planned to start by putting in place a comprehensive system found it necessary to abandon the effort and to work instead toward more modest, intermediate milestones.

Each company had different strengths on which to build. Most began with a pilot integration project in one division, typically the one with the greatest willingness to take the risk of making the technological and organizational changes required for CIM. Managerial organization often is an impediment to computer integration, particularly if lines of communication do not exist among the appropriate parties.

FEDERALLY FUNDED CAD/CAM PROGRAMS. As part of the study, the Committee met with the managers of the three major government programs that relate to computer-integrated manufacturing: the NASA/Navy Integrated Program for Aerospace Vehicle Design (IPAD); the Air Force's Integrated Computer-Aided Manufacturing (ICAM) program; and the National Bureau of Standards' Automated Manufacturing Research Facility (AMRF).

The three federal programs directed at the integration of computerized systems in engineering design and production are directed at the solutions of problems that much of industry faces. No single program, however, has addressed the integrated system as a whole. Rather, IPAD addresses engineering design, ICAM addresses the architecture of manufacturing and the control of production, and, the AMRF assists medium-sized and other companies to use shop-floor automation.

Federal technology programs tend to be reasonably applicable to many companies and therefore exactly applicable to none. Thus, companies seeking to integrate can find many useful technological accomplishements in these programs, but each company must customize its own integrated system. To the extent that these companies have access to information on technological accomplishements elsewhere, creation of a CIM system will be easier.

Integrated Program for Aerospace Vehicle Design (IPAD). The initial objective of the Integrated Program for Aerospace Vehicle Design (IPAD) was to develop a computer software system for use by the U.S. aerospace industry in the design of future vehicles. This system was intended to reduce time and cost substantially and to foster improved vehicle performance.

The work began in 1976 at the Boeing Commercial Airplane Company with the preparation of specifications and preliminary design for an IPAD system. It was to support the full engineering activities of a large aerospace organization composed of many people working on many projects at several levels of design over long periods of time.

The requirements were for a general purpose: an interactive computer-aided engineering system capable of supporting engineering data associated with the design process and its interfaces with production. The system would serve management and engineering staffs at all levels, including the production process.

The preliminary system design focused on a distributed, heterogeneous machine environment in which data base management technology and networks played critical roles in the total solution. In 1978, NASA decided to concentrate IPAD resources in two areas: data management and networking between heterogeneous machines.

Large improvements can be made in the way information is managed and shared, which IPAD demonstrated in its data base management system prototype, called IPIP. It is a multimodal, multiuser, multilevel schema, concurrent access DBMS that includes the data definition language (DDL) and data manipulation language (DML) required to solve engineering problems. IPIP supports multiple data models (relation, hierarchy, and network). These features promote a high degree of data independence.

The IPAD network system provides ultra-high-speed exchange of data between heterogeneous equipment. It provides the equivalent of levels 3 through 6 of the International Standards Organization (ISO) seven-level model communications. The system was the first to use Network System Corporation's Hyperchannel to provide process-to-process communications (levels 1 and 2 of the ISO model) between different computers (a VAX 11/780 and a CDC CYBER 835) using different operating systems. In Summary:

1. The IPAD studies of engineering processes provided a broad understanding of the system requirements that will have to be supported to reach integration.
2. The IPAD research work provided useful prototype software for advanced network communication and engineering data management, illustrating the nature of future products.
3. IPAD tutorials, reports, and applications established the advanced technology requirements of engineering data management, data schema, and integration of engineering applications with an engineering data management system.
4. The development of a software prototype helped stimulate vendors to produce new products in the areas of data management and network communications.

Recent NASA reviews of the projects led to the conclusion that IPAD had fulfilled to a large extent its original research objective. Consequently, NASA and Boeing are formulating a redirection of the project.

Integrated Computer Aided Manufacturing (ICAM) While NASA and the Navy have sponsored IPAD, an engineering design system, the Air Force has sponsored the Integrated Computer Aided Manufacturing (ICAM) program, a production system. Both types of systems are required for computer-integrated manufacturing.

The Air Force created the ICAM program in 1976 to achieve major increases in productivity in aerospace batch manufacturing through widespread application of computer-based, fully integrated factory management and operation systems. ICAM had a nine-year budget of almost $100 million. The demonstration of an integrated sheet metal center at Boeing Military Airplane Company in 1985 will culminate the program.

The Air Force approach was to create integrated management systems that tie all of the key production functions--product development, production, and product support--into a common data base. Production, the principal concern for ICAM, includes planning of facilities, assembly, fabrication, quality control, and data collection.(2)

Early efforts were directed at identifying the key barriers to more effective integration. Through the use of industry/university consortia, ICAM then identified and demonstrated ways to break down these barriers in the industrial environment. Additional effort is directed at transferring the technology.

Product Definition Data Interface (PDDI). Perhaps the most formidable technological barrier to CAD/CAM integration is the transfer of geometry and instructions across the design-production interface. The government program addressing this barrier most directly is the Product Definition Data Interface (PDDI) project within the ICAM program. It seeks to provide a framework for exchange of digital data defining the geometry of the product, which serve the function of the conventional engineering drawing.

The Initial Graphics Exchange Specification (IGES), managed by the National Bureau of Standards, established the initial base for direct digital exchange of graphics data. It has been adopted as a standard by the American National Standards Institute (ANSI Y14.26M, Section 2-4) and is being used by major vendors and users.

IGES provide a product definition data interface for limited applications. Full integration will require a complete product description that is accessible and understandable by users at all points in the manufacturing process. Advanced manufacturing technologies in numerical control, robotics, automated process planning, and inspection, and their integration into a cohesive system, are practically impossible if the product cannot be defined by digital data that can directly feed these processes.

The PDDI project is likely to extend the applicability of IGES considerably. Its objective is twofold. First, it will identify the current state of IGES implementation through the application of test procedures for current graphics systems. Second, it will define long-range manufacturing needs and demonstrate a prototype interface for product definition data that meets these needs. To these ends, the project will:

1. analyze needs for product definition data in manufacturing using sample aerospace aprts,
2. define an automated framework for a Product Definition Data Interface,
3. develop a data format and utilities required to support the PDDI, and
4. prove the concept of the PDDI through demonstration of the utility software.

The PDDI prototype system is intended to serve as the information interface between engineering and all manufacturing functions that use today's blueprint, including process planning, numerical control programming, quality assurance, and tool design. It will be demonstrated with an advanced programming system and an advanced process planning system. The system also will be operated by two commercial CAD systems to demonstrate its general applicability.

Automated Manufacturing Research Facility. The Automated Manufacturing Research Facility (AMRF) of the National Bureau of Standards serves as an engineering "test bed" to supply U.S. industry with "new ways of making precise measurements of machined parts derived from NBS standards that will be developed using capabilities inherent in modern, computer-controlled machinery." A second objective is to encourage the modernization of U.S. industries through the development and common use of standard interfaces between various types of equipment.

Standard interfaces would enable heterogeneous components of a manufacturing system to communicate without a need for custom-designed interfaces. The challenge is to develop standard procedures, protocols, and interfaces that will support current and emerging technology without stifling innovation.

The AMRF seeks the most practical incremental route to automation for small to medium sized companies. It uses domestically built, comercially available machines, most of which involve two or more components made by different manufacturers. The modular, hierarchical software is believed by NBS to be the most flexible program available today. The program was first demonstrated in November 1983, and enhancements are planned over the next two or more years.(3)

AMRF research is aimed at inspection of parts while they are being processed. With advanced machine-control systems and new computer technology, the computer can be programmed to compensate continually for known errors in machine movement, using sensors to determine machine condition. An important question still to be answered is how to calibrate precisely a measurement process that is deeply embedded in the manufacturing process and that may depend on the machine-tool control system.

Most large industrial firms now have heterogeneous computer-controlled equipment and the skills and resources to work out the complex interface problems of integration. However, 87 percent of discrete parts manufacturing companies have fewer than 50 employees. Smaller companies, with limited resources, cannot invest in large scale automated systems all at once. Yet large companies that purchase parts from smaller companies find that their own CIM efforts are slowed by their supplier's lack of CIM abilities.

Because the AMRF system is a research facility to be used government, industry, and academia to evaluate different systems concepts, it has an emulation capability. Emulation is the ability to perform the computer functions of one computer or hardware element in another computer so that, from a logical basis, the rest of the system does not recognize the substitution. Any piece of equipment, group of machines, or subsystem can be caused to emulate another subsystem, so that the AMRF hardware and software can be used to evaluate a system using alternative choices of hardware and software.

ISSUES THAT INFLUENCE COMPUTER INTEGRATION. A number of issues can affect a company's willingness to pursue computer integration, the approach taken, and the likelihood of success. These issues can be categorized as technical, organizational, financial and accounting, and governmental. While many of the issues can be seen as barriers to computer-integrated manufacturing, recognizing them can provide opportunities to facilitate progress toward integration.

TECHNICAL ISSUES. Many problems perceived by organizations considering integration can be addressed with existing integration technology, but a number of important technical barriers remain. Before computer-integrated manufacturing can reach its full potential for increasing productivity in both design and production, technical advances are needed in the following areas:

- data communication in a system in which both hardware and software are heterogeneous
- validation and consistency of data
- representation of integrated textual geometrical data
- expert system and artificial intelligence
- analytical models of manufacturing processes.

These advances are listed in the probable increasing order of difficulty, but their relative importance will vary among companies, depending on company size and products. As the advances are realized, the implementation of the first three must be standardized within many organization if they are to be effective.

Data Communication. The data communication problem in CAD/CAM exists at three levels, as in many other complex computer systems. At the first level is communication between different programs running on a single computer. This problem primarily involves data format and integrity and is not usually considered a communication issue. Companies small enough to be able to meet all their design, analysis, machine control, testing, and management needs with one computer will have only this level of communication problem.

The second level of communication problem occurs between computers of a single brand. Most large vendors of computers offer a mixture of hardware and software that allows some level of communication between their different products. The communication media can be chosen to meet the requirement of the factory, while providing the required control response times.

The third level of communication problem is to provide communication among a variety of systems from many manufacturers. Such interchange can be achieved only if each pair of communicating systems uses a common protocol for communication control and representation of data. If the number of different systems (N) is large, then it is impractical for the vendor of each system to provide the N-1 specific protocols and keep up with any changes. Hence it is important to have a single protocol that each system can use to talk to all others.

The International Standards Organization (ISO) has defined a model for Open Systems interconnection (OSI) that directly addresses this problem and is in the process of defining detailed stardards for the required protocols. The National Bureau of Standards and General Motors Corporation have been promoting, through separate but coordinated efforts, the implementatin of these protocols by a number of computer vendors. The effort led by the NBS is sponsored by Boeing Computer Services and is aimed at demonstrating the compatibility of different vendors' implementations of a common protocol. The GM effort, called MAP (Manufacturing Automation Protocol), investigates the use of standard protocols to communicate manufacturing control files and status information among minicomputers and small systems like programmable controllers.(4)

At the 1984 National Computer Conference, both systems demonstrated limited transfer of files among computers built and programmed by different vendors (Digital Equipment, Hewlett Packard, IBM, Motorola, Gould, and Allen Bradley). These standards will permit users to choose the best systems in terms of cost and application, while being reasonably confident that intersystem communication is possible. The GM effort is very important; it was gaining considerable acceptance by both users and vendors as this report was nearing completion and appears on its way to being a useful industry standard.

The NBS and others are working on procedures to test the conformity of indivisual systems to the protocol standards, so that eventual purchasers can have confidence that a mixed vendor system will work. A number of computer vendors whose products are used for graphic design, analysis, and management are also considering offering these ISO standard protocols.

Validation and Consistence of Data. The validity and consistency of data in a manufacturing data base must be assured if it is to be a reliable and comprehensive source of manufacturing information. Unreliable and inconsistent information is probably worse than no information. Traditional data processing has had separate data files for each application program. As a result, manual or automatic data translation between files has been needed, and data were often inconsistent. It is now widely accepted that data files should be separated from particular application programs by limiting data access with a common set of data management routines that preserve accuracy and consistency.

Validity generally means that all data entered into the data base obey any direct or calculated constraints imposed on them. This shifts the burden from the person or process entering the data to the formulation of the constraints, which must be accurate and tight enough to be effective, but not so tight as to inhibit legitimate change. Effective constraints will reflect models of product characteristics or process performance. One vendor has developed primitive automatic constraints on the designer, based on the capability of the production machinery and the material being fabricated.

Consistency means that a change in one data item is accompanied by changes in related data items. It is enforced by prohibiting the entry of inconsistent data or by recalculating dependent information. Although recalculation is feasible for simple constraints, in many cases the constraint calculation may require too much time, or the nature of the constraints may not be understood well enough to be expressed in current software technology.

Whether data are dependent or independent will depend on the point of view of the user. Part geometry, for example, is the independent variable from the point of view of the designer and dictates the process required to make the part; the manufacturing engineer, on the other hand, may view the available tooling as the independent variable that should constrain the part design. Most companies treat this as an organizational issue because techniques that provide for this multidirectional dependency are not yet well developed. Another consistency issue arises when changes by different people at different times are not coordinated.

Many of these problems can be handled with automated versions of existing sign-off or release systems. These systems, for example, allow only one individual to change the master copy of a design file; all other copies are considered unofficial working copies and used at the risk that the official version may change. The IPAD program began to deal with this problem in a distributed heterogeneous environment of computers and data base software.

Text/Geometry Integration. Most Computer-based graphic design systems originated as more effiecient ways to create conventional drawings. The intent was to provide efficient and accurate storage of enough information to recreate or modify a drawing; generally, no attempt was made to make the stored information usable by other systems.

As improved technology became available to analyze the functional behavior (e.g., strength, vibration, aerodynamics, heat transfer) of a mechanical part or assembly, it made sense to use the same data files for analysis that was used to generate drawings. This eliminated duplication of data entry and the possibility of inconsistency between the two data sets.

A further step is to use geometric informatino for production more directly--to use descriptions of sheet metal geometry, for example, to calculate die designs, or use descriptions of part geometry directly to calculate tool paths for numerically controlled machine tools, or calculate drill patterns for printed circuit boards directly from the file that defines the metal patterns. The objective is to extract the required information automatically from the computerized, graphical representation of an object.

If the information required by the production group is known in advance, algorithms (and therefore computer programs) might be constructed to obtain it from the model. However, the amount of semantic information carried by the graphical representation (and potentially required for fabrication) is very large; it is impossible to prepare in advance a sufficiently complete set of programs to answer all the queries that may come from the production group. Indeed, it is difficult to construct algorithms that yield answers to such simple queries as "what are the dimensions of the pockets to be milled?" or "which webs are thinner than 0.05 inch and higher than 0.5 inch?" It is quite difficult to construct a completely integrated CAD/CAM system in which the graphical representations of objects can be treated on a par with numerical or textual information whose semantics can easily be extracted as long as such data follow a prescribed format or syntax. The PDDI project is addressing the problem of making it clear to extract manufacturing process information from the design data base.

Currently, queries from the production group are handled by engineers looking at a drawing. These manual operations are a major impediment to the development of an integrated manufacturing system. Replacing them by a computer program will require considerable research, involving pattern recognition, scene analysis, graphic modeling, and artificial intelligence.

Expert Systems. The companies visited by the Committee viewed artificial intelligence as a long-term, not current, need as they work toward CIM. Artificial intelligence is the part of computer science that is concerned with the symbol manipulation processes that produce intelligent action; intelligent action