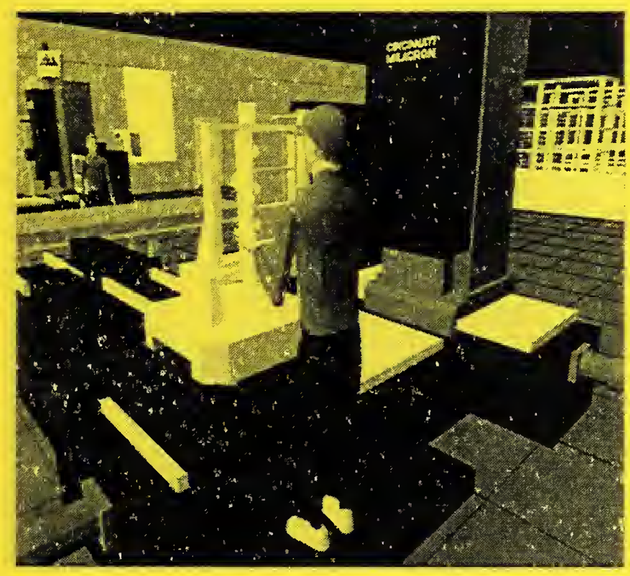
NISTIR 6142

NIST Manufacturing Process Planning and CAME Workshop

Workshop Proceedings
Marriott Hotel, Gaithersburg, MD
June 10-11, 1996



Mike Smith
Swee Leong
William Regli

Sponsored by the

U.S. Department of Commerce
Technology Administration
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U.S. DEPARTMENT OF COMMERCE
William M. Daley, Secretary

TECHNOLOGY ADMINISTRATION
Gary R. Bachula, Acting Under Secretary for Technology

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
Raymond G. Kammer, Director

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ACRONYMS

AI	Artificial Intelligence
AP	Application Protocol
API	Application Program Interfaces
BPR	Business Process Re-engineering
CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
CAME	Computer-Aided Manufacturing Engineering
CAPP	Computer-Aided Process Planning
CMM	Coordinate Measurement Machine
CORBA	Common Object Request Broker Architecture
Cyc	A knowledge-based product by CyCorp
DCE	Distributed Computing Environment
DFx	Design for Manufacturability, Design for Manufacturing and assembly, etc.
ECO	Engineering Change Order
EDM	Engineering Data Management
ERP	Enterprise Resource Planning
IDL	Interface Definition Language
IGES	Initial Graphics Exchange Specification
ISO	International Organization for Standardization
IT	Information Technology
KA	Knowledge Acquisition
MES	Manufacturing Execution Systems
MRP	Materials Requirement Planning
NC	Numerical Control
NIST	National Institute of Standard and Technology
NSF	National Science Foundation
OLE	Object Linking and Embedding
OMG	Object Management Group
OO	Object-Oriented
PC	Personal Computer
PDM	Product Data Management

PP	Process Planning
ROI	Return of Investment
R&D	Research & Development
STEP	Standard for the Exchange of Product Model Data
VLSI	Very Large Scale Integrated Circuit
VRML	Virtual Reality Modeling Language
WWW	World Wide Web

WORKSHOP OVERVIEW AND OBJECTIVES

The 1996 Process Planning Workshop and Computer-Aided Manufacturing Engineering (CAME) Forum convened June 10-11, 1996, in Gaithersburg, Maryland. The workshop was sponsored by the National Institute of Standards and Technology (NIST), the U.S. Navy Manufacturing Technology Program and the Defense Advanced Research Projects Agency (DARPA). Invitations to participate in the workshop were extended to participants in earlier workshops held as part of the Process Planning Workshop Series and previous technical meetings of the CAME Forum.

Eighty individuals from the research, software development/vendor, manufacturing, and government communities attended the workshop. Of non-government attendees, about half were from the academic research sector, about 30% were manufacturers, and the balance was application software developers/vendors. A list of workshop participants is provided in Appendix A. Abstracts submitted in advance of the workshop by many invitees helped shape the workshop objectives and content. Participants' interests covered a range of process planning and manufacturing engineering topics including

- Features, AI/Process Planning, NC machining
- Systems integration and deployment
- Process modeling and representation
- CAPP as a critical-path tool in software supporting concurrent/collaborative engineering

Workshop objectives were formulated to address the expressed interest of participants and the specific goals of NIST's Manufacturing Engineering Laboratory. The objectives of this workshop were to

- Identify research and development issues and directions
- Determine research critical points
  - ⇒ Features/Feature Recognition
  - ⇒ Integration standards and APIs
  - ⇒ Interfaces to CAD, simulation, scheduling
  - ⇒ Other topics as appropriate
- Provide a rich technical interchange with colleagues and collaborators **across perspectives**
- Collect opinions and find common needs
- Update the status of ongoing programs

The two-day workshop was designed to promote interaction and sharing among workshop participants. The workshop design sought to enable and facilitate collaboration between industrial counterparts; between industry and academia; and among industry, academia, and NIST participants. The design provided opportunities to report the status of NIST and other research and development (R&D) programs and to learn the R&D needs of the manufacturing community. It provided an opportunity to inform funding agencies about program needs and program progress. Finally, the workshop was designed to be self-documenting to the greatest extent possible so that workshop proceedings could be prepared and disseminated using materials developed by workshop participants.

Figure 1 illustrates typical relationships among groups represented at the workshop. These groups' interests and perspectives are summarized briefly below:

- ***Users*** (manufacturers) need process planning and integration tools that make them competitive. They are the markets for developers' and vendors' products and services and they create the need for new technologies and innovation.
- ***Developers/vendors*** respond to market demands by creating new process planning and manufacturing integration tools and services that make manufacturers more competitive. They build on ideas and proven concepts provided by the research community.
- ***Researchers*** find new ways to look at manufacturing issues and opportunities and discover, invent, and demonstrate concepts and technologies that can improve manufacturing competitiveness.
- ***Government Agencies, Industry Associations, and Standards Organizations*** seek to establish relationships, incentives, mechanisms, and standards that help researchers, developers, and users converge on high value-added tools and technologies that enhance manufacturing competitiveness.

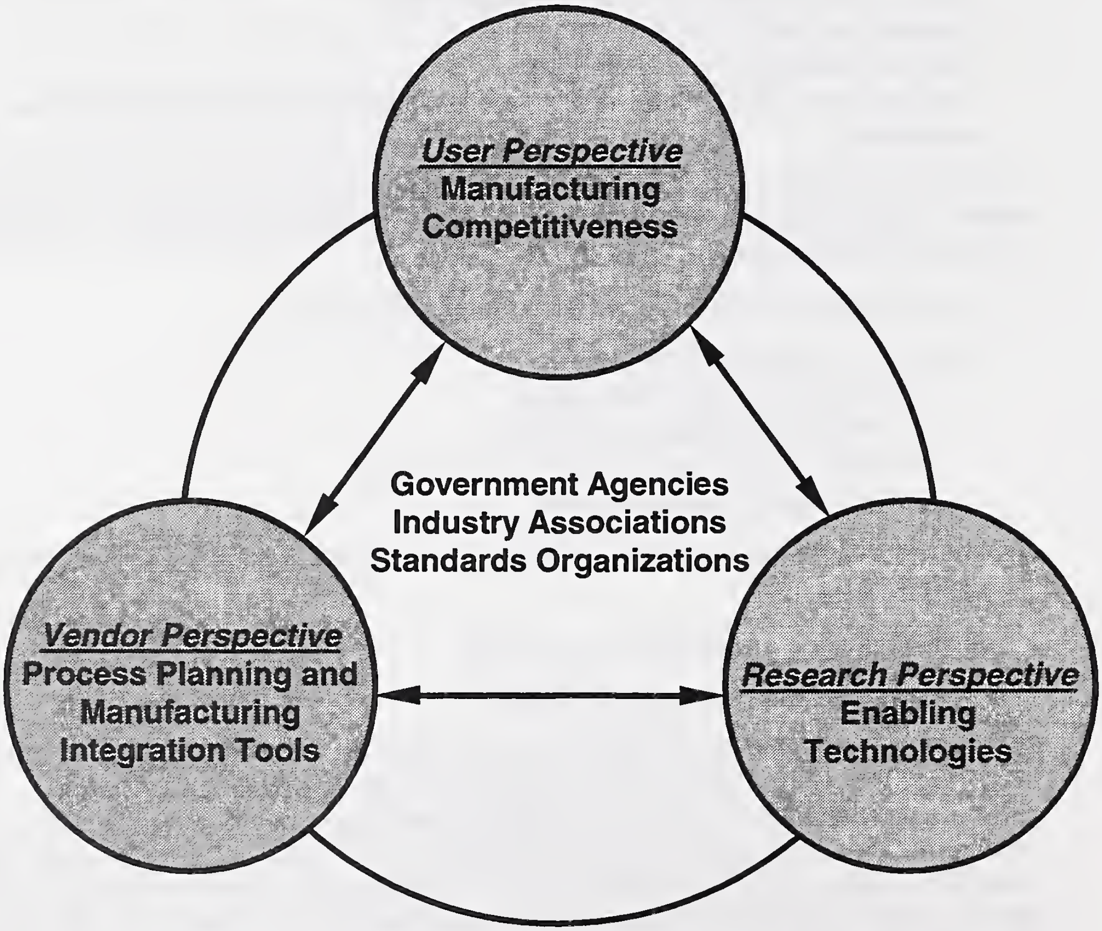


Figure 1. Relationships Among Manufacturing Stakeholders

The workshop was organized around a series of four breakout and report back sessions. The sessions were interleaved with keynote addresses by distinguished speakers from the research and development and application software vendor communities. Appendix B shows the detailed agenda for the workshop. Table 1 describes the four breakout session topics, the composition of the breakout groups, and the desired outcome of each breakout session.

Table 1. Overview of Workshop Breakout Sessions

Breakout Session	Description	Groups	Desired Outcome
I Monday, 10:15am - 11:45am	Discovery session to identify and assess technologies, tools, and needs.	Organized around research, development, and user perspectives	Assessments of identified technologies, tools, and needs
II Monday, 2:00pm - 3:30pm	Probes into specific areas likely to influence the course of technology development and application	Self-selection	Insights into strategic directions for IT, business culture, and application domains
III Tuesday, 9:45am - 10:45am	Explore specific technologies of interest to workshop participants	As Assigned and self-selection	Interchange of R&D and applications status of current and emerging technologies
IV Tuesday, 1:00pm - 2:30pm	Identify and recommend roles and activities for each segment of the manufacturing stakeholder community	As Assigned -- mixed groups of researchers, developers, users, and agencies/organizations	Recommended roles and near to mid-term activities

As stated in the breakout sessions, the data presented in the table was provided in its raw form. Because of the number of concurrent activities, the editors were unable to participate in all of the data collection sessions. Corrections and expansions were made wherever possible.

PROGRAM BACKGROUND AND UPDATE

This meeting brought together the Process Planning and the Computer-Aided Manufacturing Engineering groups interested in common manufacturing-related issues. Many attendees were participants in one or more of three previous workshops in a series of Process Planning Workshops. Two of the previous process planning workshops sought to collect ideas and establish consensus within the academic process planning community. The third workshop brought together software/system vendors and manufacturers/contractors to discuss the functionality of process planning systems, the integration of process planning systems into the larger manufacturing system environment, and the obstacles to and opportunities for the introduction of new technologies for process planning. Proceedings of the most recent Process Planning Workshop are documented in a NIST report.[1]

Other workshop attendees are members of the CAME Forum. CAME Forum members include university-based researchers, software developers and vendors, manufacturing engineers, and manufacturing managers. The CAME Forum met twice previous to this workshop to examine issues relating to manufacturing engineering data generation, data validation, and to evaluate progress in development of a manufacturing engineering toolkit (METK). Proceedings of the most recent CAME Forum Technical Meeting are documented in a NIST report.[2]

CAME Forum Update and Program Overview

Chuck Mclean provided an overview of the Computer-Aided Manufacturing Engineering (CAME) program. The CAME program is placing an emphasis on providing an integrated Manufacturing Engineering Tool Kit (METK). The objectives of the METK project are to (1) define interfaces and integrate software tools for planning machined parts and, (2) develop and test a methodology for validating manufacturing engineering data using commercial off-the-shelf software. He described the system's software modules, the capabilities and contributors of the tool kit project. He announced the CAME consortium that would address the engineering tool integration and manufacturing data validation issues. Mr. McLean's briefing slides are provided in Appendix C.

Manufacturing Process Planning Update

Dr. Steven Ray provided a summary of the three prior Process Planning workshops, and briefly discussed the structure and rationale for the current workshop. He described ongoing research as part of the NIST Manufacturing Process Planning Testbed project, and identified the suite of commercial software systems available at NIST for use by staff, visiting researchers, and collaborators. Specific NIST activities include the

[1] Steven R. Ray, editor, *Proceedings of the 1993 Industrial Process Planning Workshop*, Report Number NISTIR 5284, U.S. Department of Commerce, Technology Administration, National Institute of Standards and Technology, Manufacturing Engineering Laboratory, Factory Automation Systems Division, June, 1993.

[2] Michael C. Smith and Swee Leong, editors, *Computer-Aided Manufacturing Engineering Forum, Second Technical Meeting Proceedings*, Report Number NISTIR 5846, U.S. Department of Commerce, Technology Administration, National Institute of Standards and Technology, Manufacturing Systems Integration Division, August, 1995.

creation of an Internet repository of manufactured part designs (http://www.parts.nist.gov/parts), an online bibliographic citation database (http://www.nist.gov/msid/projs/pptb/homepage.html), standardization activities related to ISO 10303-213 ("Process plans for NC machining"), and an effort to define a general process specification language (http://www.nist.gov/psl). Dr. Rays briefing slides are provided in Appendix C.

KEYNOTE ADDRESSES

Process Planning: Capturing the Imagination, Dr. David Bourne, Robotics Institute, Carnegie-Mellon University

Dr. Bourne, representing the research community, discussed the Automated Bending Expert (ABE) developed at the Robotics Institute. Using the theme "Every Part is a Boundary Part," Dr. Bourne begin with a discussion of the general process planning approach and described the problems associated with process planning for a complex sheet metal component and operations planning for a single machine. He discussed elements of sheet metal bending including robots, tools, backage contacts, and loading/unloading fixtures, and the machine operations sequence. The generative process planning approach embodied in ABE derives from first principles, such as developing unambiguous language for specifying a bending operation and identifying a near optimal plan for completing multiple bending operations (e.g., based on feasibility, handling requirements, and time.)

Dr. Bourne identified several of the research challenges associated with sheet metal fabrication process planning. These include

- recognizing the "right" features that define part geometry
- understanding the interactions among features
- sharing features between process domains (e.g., tooling features with grasping)
- developing machine independent process planning approaches
- accommodating tolerances in process planning

Dr. Bourne's approach is to integrate automated planning of part production on machines with engineering planning (via design software) so that the part can be redesigned if necessary and the production plan can be optimized. Dr. Bourne illustrated how information sharing between production planning and engineering design can reduce process/production planning time and increase the competitiveness of sheet metal fabrication.

Dr. Bourne's briefing charts are provided in Appendix C.

Business and Operations Requirements, Mr. Pete Buca, Parker Hannifin Corporation

Mr. Buca, a major user of engineering and manufacturing process planning design tools, described the organization, business units, products, types of industries that the Parker Hannifin Corporation serves. He described business relationships between Hannifin and its primary aerospace customers and its first, second and third tier subcontractors.

Parker Hannifin is a first tier supplier to the aerospace industries. They interact with their customers electronically. Designs and drawings are received from customers in a proprietary feature-based electronic format. Designs are prepared in-house and drawings are given to the contractors in multiple CAD formats depending on the needs of their customers and its subcontractors.

Parker Hannifin uses ProEngineer as their primary CAD platform and supports file transfer and data sharing with their customers and subcontractors. Mr. Buca emphasized the need for STEP but also cited many of the issues with STEP as it is still in development. He noted that STEP is in its infancy and cannot, at present, be used in a production mode.

Mechanical Space, Mr. Peter Brooks, Director, Mechanical Products, Bentley Systems, Inc.

Mr. Brooks provided the perspective of process planning software vendors. Bentley Systems, working with other engineering software vendors, developed a “single engineering model” approach – “Mechanical Space” – that integrates MicroStation Modeler, COSMOS/M, ADAMS, ESPRIT/MS and other products. This integrated suite of engineering and process planning software products delivers productivity-enhancing and quality-improving desktop solutions for mechanical designers, drafters, engineers, and manufacturing professionals.

This suite of tools provides 3D assembly, solid, surface, and wireframe modeling; functional modeling (stress, dynamics, thermal, and fluid mechanics); motion and mechanism analysis; automated geometric dimensioning and tolerancing; sheet metal fabrication planning; metal deformation and fabrication process planning; and data interfaces with CAM databases. Mechanical Space has over 2000 application program interfaces (APIs). It supports current and emerging data exchange standards; and, it operates across multiple platforms and operating systems.

Mechanical Space and related engineering design and process planning tools are described in greater detail in Mr. Brooks briefing charts provided in Appendix C.

BREAKOUT SESSION I -- TECHNOLOGY FUTURES (GENERAL)

Session Overview

The objective of the first breakout session was to identify and assess technologies, tools, and needs. Participants joined one of three breakout groups based on their individual perspectives – researcher, developer/vendor, user/manufacturer. Each breakout group considered a specific triggering question designed to elicit general issue relevant to that perspective. Each breakout group used a similar process of first identifying responses to the triggering question, organizing those responses into categories that served to identify trends and commonalties and to facilitate communicating results during the plenary session, and then providing an assessment of the technology in terms of technical maturity, market readiness, or competitive potential. Results of these three breakout groups are presented and discussed below.

Research Perspective

Participants from the research community addressed the following triggering question:

What are the new technologies that will facilitate manufacturing integration and process planning?

Results of the research breakout group are shown in Table 2. Discussion included product/process representation, information architecture, use of the WWW, algorithms for optimizing multiple design and manufacturing criteria, data management/ warehousing, computational efficiency, and human/computer interfaces. Each technology was discussed in relation to specific manufacturing needs and research challenges as well as an assessment of the current status of the enabling technology.

Table 2. Breakout Session I Report -- Research Breakout Group

Enabling Technology	Manufacturing Need Addressed	Technical Hurdles/ Research Challenges	Assessment*
World Wide Web	Supply Chain Management	Vendor/Distributor/ Manufacturer Relations Methods of Electronic Accounting Load Management, ease of changing suppliers (for example) based on current status Copyright analogy – bring existing methods up to speed	Basic research/ proof of principle
	Distributed Design/ Manufacturing (Contract tendering)	Security: How much data to provide? Information abstraction (Assume electronic security covered by people who know more than us)	Company Policy
Human Computer Interaction	Usability, Visual understanding, familiarity	Which level of detail to represent, and when Task balance, sometimes the computer shouldn't be doing everything Context specific representations based on current detail of model, required detail	Basic research exists, just applied to our domain (cognitive theory)
Parallel and distributed computing	Addresses accessing distributed information in real time	Algorithm parallelization, network awareness	Basic research in reformulation as a distributed problem.
Architectural Description Language	Rapid development, flexible to allow change	Making it scaleable, extensible	Proof of principle
Communication among architectural elements	Integration (internal and external)	Standardization, extensibility, inertia	Demonstration
Data Warehousing	Storage and retrieval Integration with legacy data	Culture, work required; extracting data/ Information from humans.	Demonstration, some development
Reference architecture, virtual machine	Platform/ hardware independence	Process models, understanding process buy-in, sharing without stifling competition	Basic research, demonstration
Encryption, firewalls	Security of distributed systems	Ease of use	Demonstration
Near optimization	Cost reduction, product quality, throughput	New algorithms New representations Heterogeneous optimization criteria Multi-disciplinary objectives	Basic research
Feedback	Integration – CAD/ CAPP/ CAM	Data representation, capture, delivery	Application
Agents	Dynamic planning	Human-computer interface	Basic research

* Assessment: nature of research required, e.g., *basic research* to discover principles or relationships, *proof of principle* to confirm hypothesized relationships or functionality, *technology demonstration* to show functionality, capability, effectiveness, etc.

Enabling Technology	Manufacturing Need Addressed	Technical Hurdles/ Research Challenges	Assessment*
Simulation and analysis	Cost analysis Validation Evaluation	Representation Process models Cost models Interaction – multi-domain	Basic research (next 5 years – electronic commerce)
Representation/ standards	Communications Center of integration	Complexity of capturing intent diversity Simplicity Process independent representation Linkage of product and process information	Basic research
Features (intent, product description, translation)	Translation of design representation into manufacturing action	Inclusion of tolerance information Non-machining feature	Basic research or proof of concept, depending on domain
Data mining	Extending the usability of information	Mapping various data	Basic research
All of above	Integration into a single system	Combining the technical advances Scaling, demonstrate in a real system Funding!	Demonstration

Developer/Vendor Perspective

The developer/vendor breakout group considered the following triggering question:

What are the next generation tools to support manufacturing integration and process planning?

The developer/vendor breakout group used Figure 2 as the catalyst for discussion of their triggering question. This figure shows the area where software tools can assist manufacturers in achieving a more competitive design-to-production environment. Table 3 shows the result of their discussion. Participants listed specific process planning and integration tools, noted the manufacturing needs addressed, and then identified the enabling technologies required to make the tools possible. Finally, participants assessed the current status of the tools they identified.

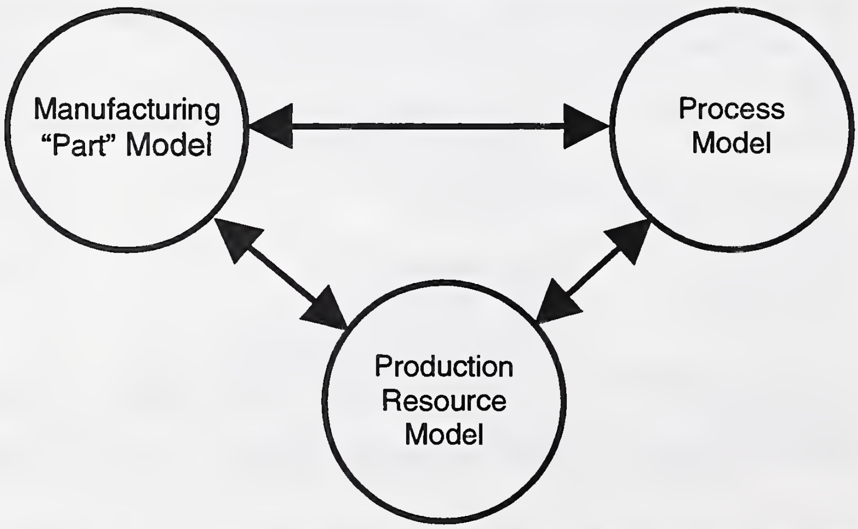


Figure 2. Process Planning and Product Data Modeling Relationships

Table 3. Breakout Session I Report -- Developer/Vendor Breakout Group

Process Planning & Integration Tools	Manufacturing Needs Addressed	Enabling Technologies (e.g., standards, Software, integration, architecture)	Assessment*
Inter-/Intranet	Delivery mechanism	WWW, JAVA, VRML	Pilots
CAD Model Standards	CAD Integration Manufacturing Model Data Representation • Features (not just geometry) • Geometric Dimensioning and Tolerances • Workpiece	STEP and Children	Inadequate
Interfaces	Integration	OLE/CORBA "Plug & play" environment Access to other vendors' data/ visualization Associativity	Not defined Proprietary
Features	Data between systems Association of methods with geometry	Need multiple levels Not just physical Parametric STEP (we hope)	"It ain't there"
Plan representation and editing	Capture corporate knowledge base Perform proprietary retrieval	Proprietary knowledge bases Structured Query Language	In-house solutions No general standards Niche markets

Manufacturer Perspective

Participants from the user/manufacturer perspective considered the following question:

What are the critical information technology needs and challenges that affect manufacturing competitiveness?

Table 4 shows results of the user/manufacturer discussion of this triggering question. Note that this breakout group addressed technology requirements from the perspective of their effect on manufacturing competitiveness.

* Assessment: status of the tool in terms such as *availability* (e.g., now, 1, 3, 5 years out), *development status* (e.g., prototype, testing, COTS), and *market potential* in terms of value and potential demand

Table 4. Breakout Session I Report -- User Breakout Group

Competitive Needs	Key IT Tools and Technologies	Business Case Elements	Assessment*
Required definition & management • Design rules of current manufacturing capacity and other "ilities" • Data exchange (product/ process capability) • Data management • Capture process knowledge	Data base software Artificial Intelligence Intelligent interoperability of component based manufacturing software	Speed Quality Cost Flexibility	
Interoperability – global plug & play	Standards User friendly interface	Reduced integration cost	
Analytical support tools • new product development • focused on cost, cycle time, market driven, user friendly, plug & play	1. manufacturing simulation systems 2. Knowledge-based systems 3. DFx systems 4. PDM systems 5. Feature-based CAD 6. Cost analysis 7. Life cycle analysis 8. Business process tools 9. Concurrent engineering – virtual enterprises	Reduce development cycle time Reduce scrap, rework Lower costs Mass customization Minimize ECOs Increase production rates	Readiness/ Affordable 1. low/low 2. low/low 3. low/low 4. med-high/med 5. med/low 6. high/low 7. low/low 8. high/high 9. high/low
Data Access and Exchange • to filter large amount of data to useful information • global information dissemination for manufacturing support • interoperability between commercial tools (plug & play) • security on manufacturing data • multimedia delivery of product/ process information • data exchange standards	Intelligent, flexible filtering systems	Improve quality Reduce time Reduce cost	

* Assessment: Indicate potential *return on investment* (payoff) and *market readiness* (e.g., willingness of users to invest) for tools that meet competitive needs.

Competitive Needs	Key IT Tools and Technologies	Business Case Elements	Assessment*
Data and Knowledge Mgmt. • quick, easy, standard methods to capture and maintain process planning knowledge • data integration of manufacturing applications • knowledge-based support tools	Data base management systems Product Data Management systems	Improve quality Reduce time Reduce cost	

Breakout Session Summary

The result of breakout session I is the combined perspectives of users (manufacturers), developer/vendors, and researchers that is obtained by looking for the commonalities across Tables 2-4. The common thread that runs through all three tables is the need for product and process data representations that can be easily exchanged across applications and platforms and the analytical tools to act on these data to support manufacturing decisions leading to higher quality, lower cost, greater throughput, and reduced cycle times. The “bottom line” is that the enabling technologies must satisfy the business needs of the manufacturing community to produce a more competitive manufacturing enterprise.

BREAKOUT SESSION II -- TECHNOLOGY FUTURES (SPECIFIC)

Session Overview

During breakout session II, participants considered three specific areas likely to influence the course of manufacturing process planning technology development and application. Participants were asked to choose one of three breakout groups to discuss one of the three following questions:

Business Culture: *How will manufacturing integration and process planning technologies affect the next business "culture" (and vice-versa)?*

Manufacturing Domains: *What manufacturing domains beyond machining are attractive targets for integration and process planning technologies?*

IT Paradigm: *What will become the dominant information technology paradigm for manufacturing engineering and process planning?*

The intent of these three questions was to elicit insights into the strategic directions for information technology as it applies to manufacturing. Importantly, participants (especially those considering the business "culture" issue) were asked to think about how business factors will influence technology development (e.g., supply chain integration). Each breakout group was asked to suggest strategic directions, provide a rationale or justification for that direction, and then assess the effect of that direction on manufacturing.

Technology and Business Culture

Participants in the "business culture" breakout group considered the challenges facing manufacturers, discussed the business factors that will affect technology development and selection, and then speculated about future directions in manufacturing that will likely affect process planning technology development. Results of their discussions are summarized below.

Challenges facing manufacturers:

1. Knowledge capture and transfer with high data security
2. High reliability authentication to ensure appropriate access to data
3. Effects of advanced manufacturing technology on the manufacturing workforce (skill base, virtual workforce, etc.)

Business factors that will affect technology development and application:

1. Globalization of both competition and markets
2. Outsourcing of selected manufacturing functions, especially to offshore sources
3. Increased use of fixed price contracts that add cost pressures
4. World class quality expectations
5. Zero inventory to achieve cost reductions but require maximum agility

6. Consolidation around core competencies
7. Intensive supply chain management
8. Virtual organizations
9. Strategic management

What is next for manufacturers and manufacturing?

1. Advanced hybrid techniques of production (mechatronics)
2. Niche specialists to augment available technology and capacity
3. Design-to-order manufacturing (e.g., VLSI)
4. "Rent-a-planner" to replace or augment in-house manufacturing planning capability (process planning and other manufacturing integration as a service)
5. Technology is a commodity; information is a commodity (e.g., easy access to both – purchase decisions based on price and delivery)

Manufacturing Domains

Participants who chose to consider which manufacturing domains might be attractive targets for integration and process planning technologies spent time discussing reasons for expanding to other domains, defining manufacturing domains, and developing an "attractiveness metric" for use in choosing target domains. This group concluded that domains should be selected based on opportunities to save time and/or money and to improve quality and/or safety.

The group discussed several strategic trends likely to cause process planning and manufacturing integration tools to expand beyond traditional metal removal domains. Table 5 summarizes these directions and the rationale for their selection. Note that Table 5 does not address specific domains but identifies trends in manufacturing that are likely to lead to new application domains.

Table 5. Breakout Session II Report Out - Manufacturing Domains

Strategic Direction	Rationale/Justification	Effect on Manufacturing
Planning for lot sizes of one	Customer demand	High cost of line change and material handling
Net shape or near net shape castings	Saves material, lower capital, leads to standardization	More volume out of same floor space, lower cost
Look at integration of manufacturing and design at front end of project		

The group offered the following results of their discussion:

Domain possibilities by type operation:

1. Assembly
2. Tubing/wire harness
3. Welding
4. Sheet metal fabrication
5. Composites
6. Forming (casting, forging, injection molding, etc.)
7. Surface finishing (plating, heat treating, etc.)
8. Inspection
9. Workflow management
10. Packaging
11. Material handling

Domain possibilities by industry type:

1. Apparel
2. Wood working
3. Chemical
4. Food products

The "attractiveness metric" offered is

$$\frac{\text{No. of parts made by technology}}{\text{Difficulty of automation}} * \text{Dollar saved by automation} * \text{Research funding available for automation} = \textbf{Attractiveness}$$

Results of the manufacturing domain discussion are summarized in Table 6. Note that in Table 6 the group identified specific domains for consideration based on their understanding of manufacturing trends and the competitive environment.

Table 6. Breakout Session II Report Out -Manufacturing Domains

Strategic Direction	Rationale/Justification	Effect on Manufacturing
1. Assembly 2. Layered Technology 3. Forming (injection molding, extrusion, forging, etc.) 4. Bending – sheet metal	***pro***: all very popular processes; many dollar saved by automation ***con***: difficult to integrate when manufacturing process is not automated	Make custom manufacturing feasible Improve performance Reduce cost Reduce production time Increase quality

The group raised several questions that they did not address during this session: How should the role of process planning be expanded to include

- design feedback?
- multi-level process planning?
- multi-domain process planning?
- supply and resource constraints?
- fused variant and generative process planning?

Information Technology Paradigms

The IT paradigm discussion group delineated a number of emerging technologies that will affect process planning tools and then developed a framework for surfacing issues and approaches that might lead to breakthroughs in manufacturing process planning. Table 7 shows the technologies they considered and why they felt these technologies will be important.

Table 7. Breakout Session II Report Out - IT Paradigms

Strategic Direction	Rationale/Justification
Structured Query Language 3, intelligent filters, advanced scripting languages	Compatible persistent storage
CORBA, OLE, DCE	Common communication infrastructure
Web technology, client/server	Geographic distribution
JAVA, virtual machines	Platform heterogeneity
Standards (e.g., feature lists) Process models (e.g., SEMATECH framework) Ontologies (e.g., Cyc knowledge base)	Shared semantics

This discussion group proposed a sequence of architectural steps that move from domain specific knowledge to an implementation strategy that cuts across domains. Figure 3 shows the product of this discussion, including areas where specific approaches are proposed and those where issues are raised that merit further investigation.

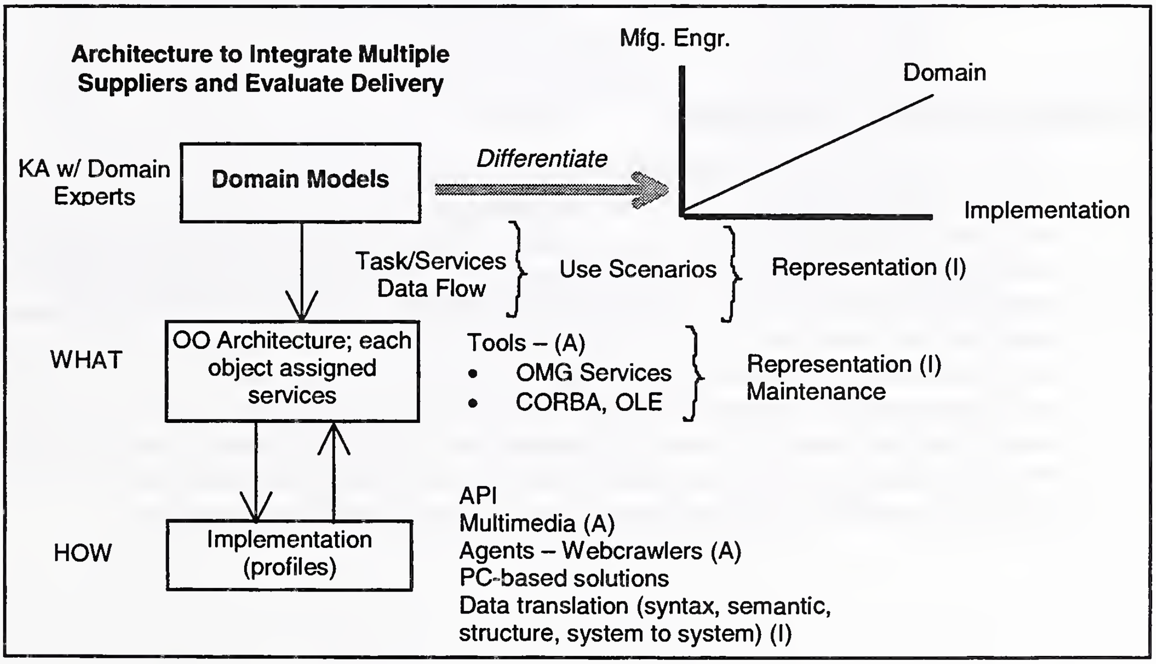


Figure 3. Approaches (A) and Issues (I) in developing the IT Paradigm

The discussion group suggested a development timeframe for enabling technologies that are essential to implementing the next manufacturing process planning paradigm. Table 8 shows this development schedule in terms of five-year development periods. Note that several key technologies are believed to be five or more years into the future.

Table 8. Technology Development Timeframe

Development Timeframe	Key Technologies
Now (0-5 years)	APIs Translators Wrappers
Near Term (5-10 years)	OLE-CORBA Infrastructure Wrappers (IDL) “Generic” Translators
Future (10+ years)	Standards Objected-oriented databases JAVA++ Shared ontologies

Breakout Session Summary

In summary, the second breakout session produced results that indicate a desire on the part of manufacturers to adopt more advanced process planning technologies but an indication that several critical technologies (including important data representation and exchange standards) are still several years off. The significant result of this breakout session is the indication that users and manufacturers understand the importance of emerging technologies to the new global, virtual, agile, and highly competitive business environment that is becoming more apparent to many manufacturers. The challenge to the IT community (research and vendors) is to work closely with manufacturers to ensure that the tools and standards that evolve in this environment are cost-effective from both manufacturing (i.e., they reduce cost and improve quality) and market (i.e., they improve agility, responsiveness, and market access) perspectives.

BREAKOUT SESSION III -- TECHNOLOGY FORUM

Session Overview

Breakout session III was designed specifically to provide an opportunity for workshop participants to exchange ideas and information about their specific research and technology interests and accomplishments. A number of participants submitted abstracts in advance of the workshop indicating particular interests; others indicated their interests by submitting the technology survey card provided at the workshop. Table 9 lists the abstract topics submitted in advance of the workshop and the individuals who submitted them. Table 10 lists the topics submitted at the workshop. Note that topics submitted at the workshop were classified into similar categories to help in forming discussion groups for the third breakout session.

Table 9. Research Topics Submitted with Pre-Workshop Abstracts

Research Topic	Submitted By
Alternative process plans and incremental process planning	Dusan Sormaz
Automated feature recognition	Bob Tuttle
Capturing feature interdependencies	Don Needham
Facility design and production scheduling and control	J. MacGregor Smith
Feature extraction and process planning	Caroline Hayes
Featured-based product representation methods	Gordon Little
Maintainable and extendible feature recognizer	Daniel Gaines
Multiple domain process planning systems	Keith Hummel
Process planning and BPR	Bill Hlavacek, Steve Haberman
Process planning for parallel machines	Derek Yip-Hoi
Quick response manufacturing	Yuan-Shin Lee
Rapid tendering and manufacture of small lots	Kenneth Dalgarno

Table 10. Technology Topics Suggested by Workshop Participants

Category	Technology Topic
Architecture	System architecture (specifically OO, agent-based)
Business Needs	Identify the potential payback/ROI for the implementation of selected integration technologies or planning systems -- this information would be useful for justifying programs to potential sponsors, vendors, users, etc.
Dynamic Integration	Integration of process planning with scheduling and other activities (dynamic process planning)
Dynamic Integration	Incremental process planning (dynamic)
Dynamic Integration	Real-time dynamic planning
Experience	Establishment of a software base providing for experimentation or demonstration of experimental PP systems (on WWW)
Experience	Estimating systems used with CAPP or as part of CAPP -- commercial systems, in-house systems. State of the art and success stories and failures
Experience	Two key elements to PP -- routing logic and estimating
Features	Solid modeling/feature recognition/manufacturing engineering/integration/associated software development
Features	Feature recognition and process planning (machining)
Features	Manufacturing features
Features	There has been a wall between feature recognition and process planning. There must be research work for destroying the wall and integrating manufacturing knowledge to feature recognition.
Features	Feature recognition, CAD-->CAM, software development, geometric reasoning
Features	Feature-based design versus feature recognition
Features	Feature recognition for real world part and integration of the whole process planning
Features	Process planning and feature extraction
Features	Tolerance representation
Integrated planning	Process plans for shop-floor control
Integrated planning	Systems planning, design, and analysis
Integrated planning	Process planning, facility layout, simulation, scheduling, and material handling design and analysis
Integrated planning	Improve manufacturing/product design relationships so manufacturing will use product design data
Integrated planning	Change propagation: The "ripple" effect that happens because of either an upstream design change or a downstream change due to manufacturing, tooling, etc.; using various software products for CAD, CAM, CAPP, etc.
Integrated planning	Integration of technologies to develop producibility and cost predictors for design systems that also suggest appropriate

Category	Technology Topic
	design changes to reduce cost and improve producibility
Integrated planning	Optimization in planning
Integrated planning	Product/process planning
Multi-domain PP	Methods/technologies for capturing and representing manufacturing data/information/knowledge for a range of manufacturing domains (not just machining). How to apply these methods/technologies to design. How are these methods/technologies adaptable to the manufacturing environment
Multi-domain PP	Process planning in distributed control structure
Multi-domain PP	Process planning of assembly products
Multi-domain PP	Identification of common research problems across planning domains. There are many common problems across various process planning domains. Some problems such as precedence constraints are "more" important in one domain (assembly) than others.
Multi-domain PP	Multi-domain process planning
Product data	Model representation - part, process, resource
Product data	Usefulness of STEP
Product data	Product data (STEP, IGES)
Product data	Process modeling specification issues
Product data	What level of data should be managed by PDM? So that data can be shared efficiently -- blob or discrete attributes?
Product data	Resource modeling
Product data	Who owns CAPP data? MRP/ERP? EDM/PDM? MES/Production?
Product data	Graphical work instructions (i.e., non-textual job plans)
Product data	Master model assembly
Research Exchange	How to improve the interactions between researchers and industries
Research Exchange	What are the different API tools desired by user/other developers/researchers from CAD/CAM systems? Discussion could be directed to system integrators
Tool Integration	Exploiting more information in the CAD model for CAD/CAM integration. What info is there? How to use? Can it be standardized? (Design history, function intent, tolerance, others?)
Tool Integration	CAD integration
Tool Integration	Integration of different modules for CAPP
Tool Integration	Multi-supplier integration -- what is needed and how do user companies make vendors comply?
Tool Integration	Design feedback
Tool Integration	Integration
Tooling	Fixture and tool design
Tooling	NC machining -- tool selection and management

After reviewing abstracts submitted in advance of the workshop as well as technology topics submitted during the workshop, seven separate discussion tracks were established and participants selected the tracks of greatest interest to them. The seven tracks are (session leaders' names are in parenthesis):

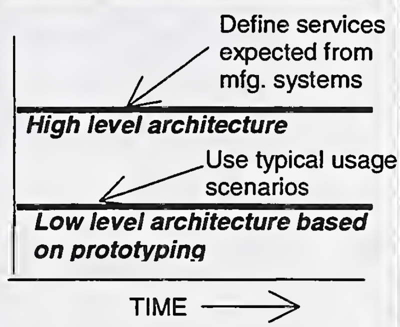
1. Architecture and tool integration (Suzanne Barber)
2. Business needs/experience/research exchange (Bill Hlavacek/Steve Haberman)
3. Dynamic process planning (Ezat Sanii)
4. Feature recognition and representation (Yong Se Kim)
5. Integrated planning (Caroline Hayes)
6. Multi-domain process planning (S. K. Gupta)
7. Product/process data (Rick Franzosa)

Each group discussed the technology and needs related to the assigned track, recorded major elements of the discussion, and made observations and drew conclusion about the status of the technology, emerging trends, and research needs. Discussion leaders provided results of the discussion either in chart form at the conclusion of the session or via electronic mail shortly after the workshop. Summary results of each of these technology breakout group sessions are provided below.

Architecture and Tool Integration

This breakout group considered the complex problem of developing architectural standards that could accommodate the variety of data flows and applications needed to support manufacturing process planning. Table 11 lists the architecture/integration topics discussed and some of the issues to be considered when addressing them.

Table 11. Breakout Session III Report out – Architecture/Integration

Integration Options	Integration & Translation	Observations/Conclusions
Integration Options • Define domain-specific and application-driven abstract interface (domain = assembly, sheet-metal; application = CAD, PP, costing) • Tools that build interface • Pay vendors • Bottom-up: integrate the world by integrating tool by tool • What can be generalized by the experience	Models to breaking barriers "Unix" model "Microsoft" model "De facto" model "De jour" model Data interoperability vs. Data privacy vs. Data exchange Buying services vs. Buying tools Application component services across domains vs. Turn key systems	 Culture change will <u>significantly</u> impact this problem.

The Architecture/Integration group concluded that there are a number of integration options and alternatives, but a major factor in the successful application of integrated process planning technologies will be the ability of manufacturers to transition from a relatively disintegrated planning approach to one that brings together multiple perspectives to consider design, manufacturing, production, supplier/distribution logistics, and other enterprise functions concurrently.

Business Needs and Experience/Research Exchange

The business needs/experience/research exchange focused on issues such as return on investment, methods for sharing experience with process planning tools, and opportunities to improve interactions between manufacturers and the research community. Their findings are summarized in Table 12.

Table 12. Breakout Session III Report Out – Business/Research Exchange

Technology Topic(s)	Major Points/Issues Discussed
Business Case for process planning	Need – what level: pen/paper, CAPP, Variant, Generative PP Architecture (Business): centralized/decentralized, World Wide Web Where does PP data go in you company? Minimize the cost of legacy system maintenance Reuse of data Capture corporate process knowledge Need tool to communicate process information to design community at time of design (tool could be a person) Insure process consistency/quality
Research/ Industry relationships	Lack of realistic test data by research Better definition of expectation at project level between research and industry; industry needs quick return on investment "Collaboratory" – send students into plants to improve industry/research relationships Companies need to put up more research $ for research (risk $) Include software suppliers as part of industry

This group discussed the business case for second generation CAPP and generative process planning and the cost and configuration of process planning systems, including the cost of obtaining or generating planning data.

Dynamic Process Planning

The dynamic process planning breakout group discussed process planning approaches that have the flexibility to accommodate changes after the initial plan has been developed. Table 13 shows the topics discussed and the major discussion points and observations.

Table 13. Breakout Session III Report Out – Dynamic Process Planning

Technology Topic(s)	Major Points/Issues Discussed	Observations/Conclusions
Dynamic PP vs. Integrated PP	Integration is an implementation issue which will be accomplished when dynamic requirements are satisfied	
Definition of dynamic PP (DPP)	A PP system that accommodates for changes in design, scheduling requirements, shop floor status, technological requirements	DPP is to be accomplished incrementally and not by complete replanning
Information requirements for DPP	Status information • Part • Resource availability (load) Scheduling data Design change information	Design change specification should be accommodated in product modeling
Architectural requirements	Needs process planning manager (to keep track of changes and instigate incremental, specific actions) Open system – accommodate for dynamic links to various other systems Modular Distributed computed	
Representation of PP requirements	Hierarchical representation	

The dynamic process planning discussion concluded that DPP must be accommodated in the product/process model architecture and DPP should be implemented in a modular, incremental manner.

Feature Recognition and Representation

The feature recognition and representation group was comprised of one user, four developers, and eight researchers. Topics addressed during their discussions include:

- Industry Needs
- Practical Use
- Other Domains than Machining
- Mapping Issues from Design to Diverse Applications

Major discussion points on these topics are:

- Industry Needs: A Case from Texas Instruments:

  Solid Model to Manufacturing Features Translation needed. What is important is volume corresponding to the removal. As typical feature-based solid modelers (e.g.,Pro/E) features are irrelevant for manufacturing and are used for part modeling purpose, translation is necessary.

  Not all the machining details are crucial, as their primary purpose is to provide machining cost estimate at design stage.

- Views on what is manufacturing feature -- discussed views were divided into two perspectives:

  What is important in features is the ability to select "processes," thus manufacturing features should contain as much details on machining as possible.

  As providing flexibility in manufacturing (machining methods) is important and typically machining details "are" filled in at later stages (e.g., NC people), shape characteristics suitable to infer machining information is important (as used in Texas Instrument).

Other remarks are:

- Process planning stage does not determine all; at NC stage the details are filled in.
- "Pocketing is more difficult than slot" as more details are to be filled in more flexible manner.
- Features are dependent of the planning (process sequence).
- Features can be general because many ways to make part.
- Flexibility is needed for high level process selection.
- There is no "design" feature which can associate such diverse design specific information as designers address diverse product concerns. Only a small portions of design decision are indicated in traditional drawings, however, much less is specified in electronic solid models.

What improvement is needed for features? (How rich the information should be tied to features)?

- Process sequence and fixture information should be tied with features.
- Machining starts with the given stock, the features should be dependent on it.
- If a stock is completely given, it is easier. But for high-level process selection, determining more effective starting workpiece for machining considering the number of parts to be produced would be more challenging.
- Intermediate workpiece (in-process workpiece) determination and its reflection in the features are necessary.
- Grouping of features based on final part shape into workpiece removal features considering rough cutting and finish cutting would be desirable.

What should be the starting information for features?

- AP203-like geometry
- Tolerance, surface finish
- Workpiece (stock)
- Process information -- is it specifiable?
    - ⇒ In Drawing, not all are specified, but only crucial information and overall general information specified.
- Current reality of the CAD/CAM Packages are far from this ideal cases.
- Should tackle current problems.

Why less feature work on other domains than machining?

- Logistics are more crucial in machining compared to other manufacturing processes.
- Thus, there are more pay-off in pursuing all the possibles in machining.
- More decomposable in machining process issues and associated cost than in other processes.
- Some processes (e.g. painting) have well-specified process plan which can be easily enhanced to a generic process specifications.
- But machining is not the case; all cases are different -- then what other applications need similar support as in machining?
    - ⇒ Inspection (e.g. CMM)
    - ⇒ Assembly - Logistics are crucial.
        - * What are the assembly features?
        - * How much of assembly information is provided/decided at design?
        - * Maybe more information is given at design stage.
        - * Need for assembly feature recognition - repair, redesign?
    - ⇒ Die Machining

Integrated Planning

The integrated planning discussion group considered problems associated with having multiple design and manufacturing process planning tools, with many unable to communicate directly with others without human intervention or re-entering data. This group discussed the problems of legacy design and process planning systems that are in widespread use but are not easily integrated with newer tools.

Results of this discussion are provided in Table 14.

Table 14. Breakout Session III Report Out – Integrated Planning

Technology Topic(s)	Major Points/Issues Discussed	Observations/Conclusions
Paradigm integrating: design and process planning	• 3D design technology is used in companies today (mostly new) • Manufacturing technology/software is older, often written in-house and can't use 3D data directly • Same is true of business process technology	• Manual tie-ins done now • Need manufacturing systems • Less urgent is the need for capability and process models ('98) • 1 bill of material
Paperless manufacturing	• Now often spend lots of effort recreating paper instructions for shop floor • Big $ investment to go "paperless" • Big step forward to accomplishing integration is "paperless" manufacturing	• Need data standards to accomplish • technology available piecemeal now
Machine tool standards/ simulation	• Want machine capabilities from maker in a standard form (data standards) for process planning users • Someone internal to company must continually tune this data to keep model correct • Tool makers (and software makers) oversell	• Need now • Helps produce resource models
Assembly	• Want to be able to quickly simulate assembly • Tools exist but one person must use everyday or skill is lost • Human-computer interface issues abound	• Flexible scenarios – automated - manual different line configurations and robot types • Fast – at the cost of some accuracy

Multi-Domain Process Planning

The multi-domain process planning group investigated other domains where process planning tools and technology might have merit. Summary results of their discussion are provided in Table 15, followed by a more detailed account of their discussion.

Table 15. Breakout Session III Report Out – Multi-Domain Process Planning

Technology Topic(s)	Major Points/Issues Discussed	Observations/Conclusions
Requirements for multi-domain process planning	• Hierarchical planning ⇒ factory ⇒ shop ⇒ workstation • Ability to handle multiple process types	• Multi-level is needed. Levels may be different for different processes • Interfaced systems need to identify functionality in each domain
Common elements	• Features taxonomy • Process capability taxonomy • Feature to process capability matching • Resource definition	• Information is quite different; for example, solid modeling will not be good for chemical manufacturing • How to represent processes for different domains?
Attractive domains	• Metal forming • Wood working • Layered manufacturing • Composite manufacturing • Apparel manufacturing • Welding/joining	• Very few systems • New systems and research are needed
Adapting design for process	• Multi-level design ⇒ process independent ⇒ process specific	• Currently do not exist • It is not entirely clear if this is achievable
Integration	• Common architecture • Common representation of plans	• Currently does not exist • Should be a major focus

Multi-Domain Process Planning

Most of the process planning research has centered around machined parts. A number of other manufacturing processes can also benefit from automated process planning systems. In this breakout session, we attempted to discuss some of the research issues that relate to multi-domain process planning systems. We mainly discussed the following four areas.

1. Requirements for Multi-Domain Process Planning

We need process planning systems that can work with processes other than machining. In many of these newer manufacturing domains it will be extremely important to first understand the desired functionality of process planning systems (i.e, what a process planning system is supposed to do?).

We will also need to have systems that can handle multiple process types. Many parts are created by a combination of processes. For example, some parts are cast first, then machined, and finally ground to create the required product. If we want create systems that can handle multiple process types, process planning systems for each process type will need to have common architecture and plan representation across multiple domains.

Process planning systems need to operate at many different levels of abstractions. We will need hierarchical systems. For example, in case of machined parts, this hierarchy will be factory level, shop level and workstation level. Depending upon the particular process, these levels might be different.

2. What are other attractive process domains of interest?

Popularity of several other processes, and advantages offered by automation make several other domains extremely attractive for automated process planning. Some of the attractive domains identified by our group are listed below:

- assembly
- wood working
- metal forming
- apparel industry
- sheet metal bending
- layered manufacturing
- composite manufacturing
- welding/joining

There exists a large body of research in assembly planning. But unfortunately, there seems to be very poor communication among assembly planning and machining process planning research communities.

3. Common Elements

A number of process planning steps (or components) are likely to be common across many of these domains. For example, in most domains we will need feature taxonomy, process taxonomy, and feature process mappings. We will also need models of manufacturing resources. In feature/process taxonomies, we should be able create common sharable structures, but the actual information may be radically different from one domain to the other. For example, solid models may be good representations for machined parts, but they may be quite inadequate for chemical mixing. Adequate representation will need to be carefully selected. Also the taxonomies should be flexible enough to allow a wide variety of manufacturing processes.

4. Adapting design across processes

Parts are usually designed with a process in mind. If the intended process changes (due to change in product demand or process innovation), one needs to modify the design to make sure that it can meet the capabilities of the new process. For example, sheet metal housings are quite different from injection molded housings. Is it possible to accomplish such a transition automatically? One way to achieve this will be to create designs at many different levels of abstractions. For example, we can create designs at two different levels. The first step will be to create a process independent design. The second step will be to create the process dependent design. Process independent designs will be common across many different process domains. We can create an automated system to create process dependent designs from process independent designs. It is not entirely clear whether or not such a translation can be accomplished automatically in the short term.

Product/Process Data

The product/process data group dealt with issues surrounding common representations of product design and manufacturing data. Their discussion covered three major topics: product and process data integration; standards; and process modeling. Results of this discussion are summarized below.

Product & Process Data Integration

Major Points / Issues Discussed

- Although ancillary systems grow in functionality and range, such systems as PDM, ERP and MES do not properly integrate at the CAPP crossroads. Typically they overlap, leading to additional problems for the process planner, not additional solutions.
- Multiple data types, and formats are the domain of the manufacturing engineer.
- System Constraints - Architectures are always changing

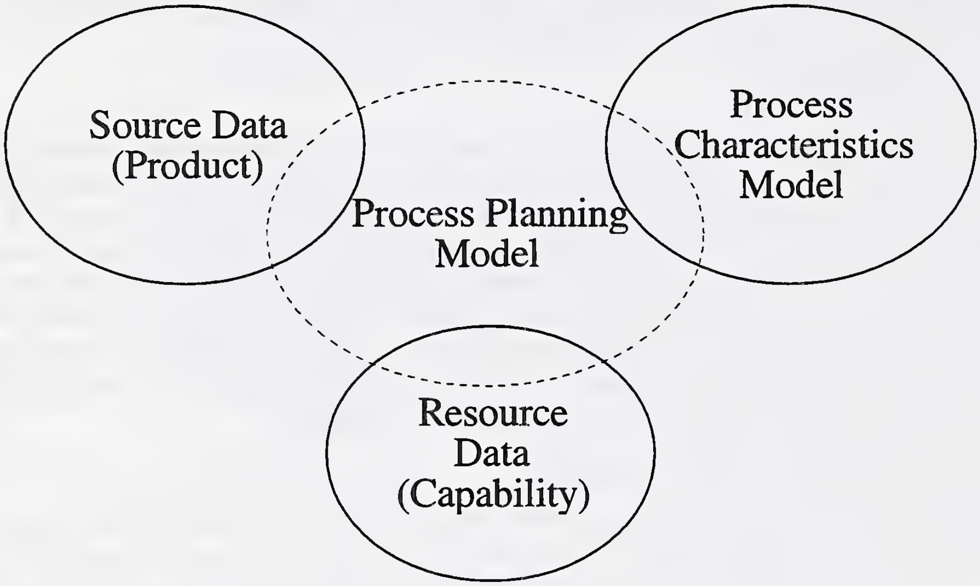


Figure 4. Process Planning Model Relationships

Observations / Conclusions

- Process planning is the glue between product, process and resource
- Need ability to manipulate, view, and deliver multiple data formats, types.
- Today's solutions are, at best, short term. Systems should be designed to reflect this, or allow incremental changes.

Standards

Major Points / Issues Discussed

- STEP's inability to fully represent real world needs, and its tendency to try and cast standards in concrete.
- STEP /Express modeling rules sometimes conflict, or are not supported by IT tools/languages. For example, some valid constructs in EXPRESS produce 'bad' C++.
- Lack of ability of standards and tool developers to provide timely, useful, cost effective deliverables is frustrating for manufacturers.

Observations / Conclusions

- Generic functions must become the basis of any process planning tool.
- Standards must be flexible, robust and amenable to change as we get smarter.
- Manufacturers can't wait and won't wait. They will just go out and do something in the absence of reliable, robust standards.

Process Modeling

Major Points / Issues Discussed

- There is a management perception that process planning systems are 'point solutions' and are not as critical (or even required) when compared with CAD/PDM, ERP, and MES systems.
- Easy to use tools can enable process planners to be more efficient.
- Automatic data movement/entry is important.
- Planner can then concentrate more on process improvement.

Observations / Conclusions

- Needs to be recognized in management that manufacturing engineering and process planning are major functions, on a par with the other applications.
- Major cost drivers are decided by manufacturing engineering.
- Business process understanding could be a remedy.

Breakout Session Summary

The technology breakout session succeeded in providing an opportunity for interested parties to exchange experiences, concerns, accomplishments, ideas, and research plans. Generally, several perspectives (developer/vendor, user/manufacturer, researcher, government agency) participated in each discussion group so that a broad view of the topic emerged. Because of their diverse nature, no attempt was made to find a common theme across all of the discussion topics but informal discussions among breakout group participants provided common ground for building future relationships. Participants expressed frustration in having limited time to explore these difficult manufacturing issues in detail but the topics discussed and the relationships formed provide an opportunity for individuals to pursue mutual interests in greater detail in other forums.

BREAKOUT SESSION IV -- ROLES AND ACTIONS

Session Overview

The final breakout session was design to encourage participants to think seriously about how each group represented at the workshop could best contribute toward resolving the difficult research, development, and implementation issues raised throughout the workshop. Breakout groups were formed around the four major perspectives represented at the workshop, namely manufacturers (users), developers/vendors, researchers, and government/standards agencies. Breakout groups were formed so that each perspective was represented in each of the breakout groups and each group was given a triggering question to stimulate discussion. The four breakout groups and triggering questions were:

Users/Manufacturers: What is the appropriate role of users/manufacturers in addressing manufacturing integration and process planning needs?

Gov't/Stds Organizations: What is the appropriate role of government and standards organizations in addressing manufacturing integration and process planning needs?

Development/Vendor: What is the appropriate role of developers/vendors in addressing manufacturing integration and process planning needs?

Research: What is the appropriate role of the research community in addressing manufacturing integration and process planning needs?

Users/Manufacturers Roles and Actions

The user/manufacturer role was characterized in terms of the following three major topics:

- Identify research issues
- Create generic interface specifications between CAD and process planning
- Identify function requirements and uses for process plans

The role of users/manufacturers in developing process planning tools was illustrated as shown in Figure 5. Users/manufacturers are in the best position to identify the practical problems associated with process planning and to determine if these problems are company-specific or application-specific or whether they have general applicability across a number of companies and/or application domains. General problems are best addressed in a broader context than a single company but do require the support, acceptance, and participation of the user/manufacturer community to ensure that they are formulated and developed properly. Company-specific problems can be classified according to the level of risk associated with solving the problems and applying the solutions. Low risk, easily-applied solutions can be addressed using in-house resources; higher risk problems require broader participation from the research and development community to provide access to the appropriate skill base and to spread risk across a larger number of participants.

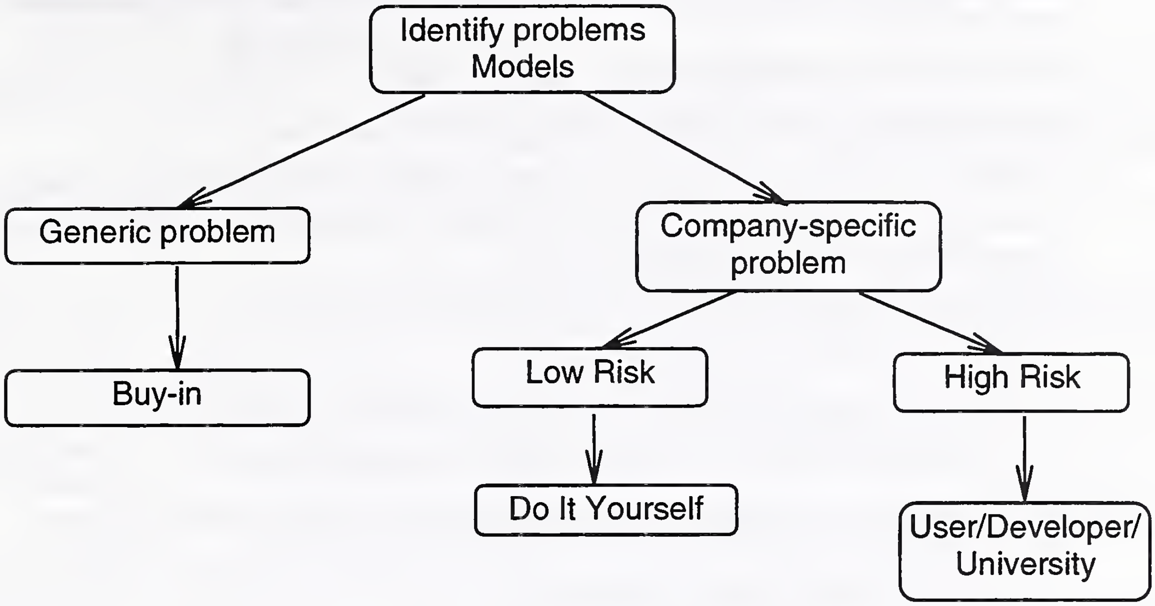


Figure 5. Decision Tree for User/Manufacturer Role in Process Planning Development Activities

In addition to identifying and addressing process planning problems, users/manufacturers fill several additional roles, including:

- Process knowledge base for designers
- Design by features
- Create feature-based process plan
- Process capability library
- Best practices framework
- Design guidelines
- Integration benchmarks
- Create incentives for manufacturers to work together
- Drive vendors to create cost effective solutions

Government/Standards Agencies Roles and Actions

The group considering the government/standards agency roles and actions agreed that these organizations cannot tell individuals or organizations what they must do except through incentives and other mechanisms that encourage compliance with widely accepted practices and standards. The group identified 21 topics where government/standards setting agencies can play a significant role, organized these topics into six major areas, and then proposed near term actions to help agencies fulfill these roles. The initial 21 topics are:

1. Work with individual and university in developing vision of process planning and manufacturing integration direction for the future; identify standardization needs to accomplish this.
2. HELP define and articulate true manufacturing needs.
3. Create standard parts for testing functionality of various systems.
4. Organize a professional society for the advancement of process planning systems.
5. Provide for a repository and test bed functionality to assist in the development of advanced tools and technologies.
6. Encourage or spearhead standards for CAD data interchange.
7. Fund high risk-high payoff activities.
8. Manage maintenance of standards for various elements of CAPP.
9. Try to bring together major vendors for standards development.
10. Provide funding for a few key projects characterizing/identifying needs for main elements of CAPP.
11. Provide advice/analysis/review of research.
12. Jointly fund with industry high priority research projects.
13. Serve as "quarterback" between CAPP activities.
14. Create opportunities for interaction among various perspectives (e.g., workshops).
15. Encourage development of standards for resource characterization.
16. Prototype interface specification and models to fast track standards development.
17. Provide neutral facility to support and promote the use of common representations, frameworks, and architectures. (documentation, guidance, common looks and feels).
18. Provide support for small shops.
19. Bring together an accessible library of research developed tools for use by other researchers/vendors.
20. Serve as catalyst to discern industry needs with respect to education.
21. Facilitate interactions and understanding between research, development, and end users.

These twenty-one topics were organized into the six major areas shown in Table 16 and specific near-term actions were proposed as initial steps in each of the major areas. Note that some of the twenty-one topics fall into more than one of the six major areas.

Table 16. Government/Standards Agencies Roles and Actions

Suggested Role	Topics (from above list)	Near Term Actions
Funding	(7,10,12)	• Fund pre-ballot testing of developing standards • Jointly fund (industry/government) intern programs for university and government personnel working on shop floor
Interaction	(9,4,14,20, 21)	• Identify next workshop topics • Proceedings published within 3 months • Put information on WWW with comment sheet
Leadership	(1,2,4,6,11,13, 15,)	• Articulate and prioritize R&D issues (e.g., maintain R&D hot list on WWW) • Establish standards roadmap
Test Bed/ Repository	(3,5, 8,17,19,)	• Preliminary study to establish test bed and repository requirements • Identify industrial partners for participation in testing
Standards	(1,3,8,9,15,16)	• Develop library of test cases • provide process plan preliminary format
Extension	(2,14,18,19,)	• Preliminary study to establish alternatives for providing extension services

Developer/Vendor Roles and Actions

The developer/vendor discussion group chose to look at the roles of each of the groups because of the interactions among the various perspectives. The role of this group depends heavily on the other groups because it is neither the end user nor does it do the basic research needed to produce new tools and approaches. It is inherently market-driven and must use research products that respond to user/manufacturer demand.

The group developed a list of conceivable roles for the developer community, including those listed below. Note that some items are listed as questions, indicating lack of consensus on whether or not the developer/vendor should move in this direction:

- Develop a full-featured, feature-based, cost-effective process planning system.
- Learn the business of the manufacturers (the customers -- don't need bells and whistles).
- Focus on niche markets?
- Form broader partnerships?
- Build plug and play modules.
- Identify and build modular engines (see research suggestions below).
- Make products easy to use with Windows-based graphical user interfaces.
- Submit to STEP-compliance certification.

Table 17 shows this group's proposed roles and actions for other groups.

Table 17. Developer/User Group's Proposed Roles and Actions for Other Perspectives

Perspective	Proposed Roles/Actions
Users/ Manufacturers	• State clearly what they want. • Demand certification of application system's conformance to key standards. • Initiate standards development.
Researchers	• Provide solutions. • Identify and build modular engines.
Societies	• Play active role in industrial standards setting.
Government	• Develop models, infrastructure. • Fund industry-directed research. • Initiate conformance testing of relevant standards.

Research Community Roles and Actions

The research group considered how the research community could contribute to advancing process planning. In doing so, this group identified specific areas where research is needed, but they also raised several issues that need to be addressed in a broader context to set the direction for future research work. Topics addressed and pertinent comments are shown in Table 18.

Table 18. Topics Addressed in Research Discussion Group

Topic Discussed	Issues Raised
Definition of Process Planning – dictionary/ ontology	• Need to agree on what to argue over • Structure • Example: Software Engineering – data dictionary
Data Representation	• Getting access to the data is the big obstacle to interoperability • Geometric Dimensioning and Tolerances (GD&T) • Computer-interpretable working solution • Emergent approach . . .
Applications/ requirements of new technologies	• Manufacturing "science" – draw similarities between problems • Problem classification – what techniques to apply? • Computer *assisted* process planning • Information management and feedback • Open software architectures and development environment
Institutional/ organizational issues	• Integration research cannot be done on a small scale • Academics need access to real problems • Main problems are cultural, not technical • Government typically pays for students; need coop students with industry background/support for software, knowledge, data, etc. • Little research goes beyond one year time frame • NSF reviewing • Work with industry as partners • Little return on investment for support of CAD/CAM API's • Industry is short term focused • Need requirements gathering domain education

Breakout Session Summary

This final breakout session provided an opportunity for workshop participants to set a course of action for each of the perspectives represented at the workshop. Each group developed specific ideas about the issues to address and options available. In general terms, the user/manufacturer group acknowledged its responsibility for identifying real problems and seeking help from the research community when they cannot solve them within available resources and risk tolerance. The government/ standards organizations see their roles as enablers through funding, testing, leadership, communications/interaction, and standard setting. The research community recognizes the technical challenges they face but sees many of the problems as institutional/cultural barriers to productive research rather than technical limitations. Finally, the vendor/developer community is in the difficult position of trying to anticipate the market for methods and tools so that they focus scarce resources on developing potential high-payoff research products.

WORSHOP SUMMARY AND NEXT STEPS

This workshop achieved its objective of providing an opportunity for interaction among the research, development, user, and government agency participants. While every participant was not able to present activities and/or research experience to every other participant, the format encouraged as much interaction as possible among as many as possible within the limited time available. Hopefully, these initial discussions among participants formed the foundation for building future relationships that will move process planning technology development from concept to practice.

Several activities related to the workshop are in progress or will soon commence:

- NIST's Manufacturing Systems Integration Division will use information obtained during this and similar workshops to select and integrate tools that support additional manufacturing engineering functions for than mechanical parts (e.g., assembly planning tools, manufacturing engineering planning validation tools that include inspection and testing, tools that confirm that the virtual machine geometry is within the tolerance of the design geometry).
- NIST is developing methods and models for classifying the motions required to assemble mechanical components so that they can be used to generate the Methods Time Measurement (MTM) cycle times associated with mechanical assembly.
- NIST seeks to develop information models and generic interface specifications that will enable manufacturing engineering planning and validation tools that come from different vendors, and perform different functions, to be integrated into a robust manufacturing engineering environment. Examples include
  - ⇒ Integrating additional process planning software into a process planning environment, including CAME process planning packages and tools for NC development.
  - ⇒ Developing standard interfaces that will enable and support development of process planning based on STEP AP213.
  - ⇒ Integrating Metaphase PDM system into the CAME program.
  - ⇒ Developing a Unified Process Specification Language to support exchange of process information among a wide range of software applications.

APPENDICES

A. Workshop Participants

B. Workshop Agenda

C. Program Updates and Keynote Presentations

C1. Computer-Aided Manufacturing Engineering (CAME) Program Overview Chuck McLean

C2. 1996 Process Planning Workshop and CAME Forum — **Steve Ray**

C3. Process Planning: Capturing the Imagination — David Bourne

C4. Mechanical Space — Peter Brooks

C5. Business and Operations Requirements — Pete Buca

Appendix A. Workshop Participants

NIST MANUFACTURING PROCESS PLANNING WORKSHOP

AND

CAME FORUM WORKSHOP

--List of Participants--

June 10-11, 1996
8:00 AM to 5:00 PM
Gaithersburg Marriott Washington Center
9751 Washingtonian Boulevard
Gaithersburg, Maryland 20878

Donald Bailey
Director of Industrial Programs
Ohio Aerospace Institute
22800 Cedar Point Road
Cleveland, OH 44142
216-962-3050 216-962-3120
DonBailey@oai.org

K. Suzanne Barber
Assistant Professor
The University of Texas
Electrical & Computer Engineering
24th & Speedway, ENS 240
Austin, TX 78712
512-471-6152 512-471-3652
barber@mail.utexas.edu

Dr. David Bourne
Senior Scientist
Carnegie Mellon University
Robotics Institute
Pittsburgh, PA 15213
412-268-7811 412-268-5569
db@BENDING.IMW.RI.CMU.EDU

Peter Brooks
Director, Mechanical Products
Bentley Systems, Inc.
690 Pennsylvania Drive
Exton, PA 19341
610-458-2740 610-458-1060
Peter.Brooks@Bentley.COM

Dr. Alan Brown
Carnegie Mellon University
Software Engineering Institute
4500 Fifth Avenue
Pittsburgh, PA 15213
412-268-6194 412-268-5758
awb@sei.cmu.edu

Robert G. Brown
President
Deneb Robotics, Inc.
3285 Lapeer Rd. West,
P.O. Box 214687
Auburn Hills, MI 48321-4687
810-377-6900 810-377-8125
bob@deneb.com

Peter Buca
Manager, Engineering Technology
Parker Hannifan Gas Turbine Fuel Systems Division,
17325 Euclid Ave.
Cleveland, OH 44112-1290
216-531-3000 216-531-0038
PeterVB@gnn.com

James W. Butler
Staff Technical Programmer Analyst
AlliedSignal Federal Manufacturing & Technologies
D/A24, E2H8, P.O. Box 419159
Kansas City, MO 64141-6159
816-997-5422 816-997-4094
jwbutler@kcp.com

Charles "Richard" Burdsal
System Analyst-Process Planning
The Boeing Company
P.O. Box 3707, M/S 42-74
Seattle, WA 98124-2207
206-655-0703 206-655-1191
rburd@scm1.bems.boeing.com

William D. Cain
Engineering Specialist
Lockheed Martin Energy Systems
P.O. Box 2009, MS 8201, Bldg. 9111
Oak Ridge, TN 37831
423-574-3235 423-574-5458
wdc@ornl.gov (Bill Cain)

Chin-Sheng Chen
Professor
Florida International University
Dept. of Industrial Engineering,
University Park
ECS 416
Miami, FL 33199
305-348-3753 305-348-3721
chenc@cimone.fiu.edu

Mo-yuen Chow
Associate Professor
North Carolina State University
Dept. of Electrical & Computer
Engineering
Box 7911
Raleigh, NC 27695-7911
919-515-7360 919-515-5523
chow@eos.ncsu.edu

Kenneth W. Dalgarno
Lecturer
University of Leeds, UK
Department of Mechanical Engineering,
Leeds, LS2 9JT
United Kingdom
44-113-233-2234
44-113-233-2150
menkwd@ECU-01.NOVELL.LEEDS.AC.UK

Pooja Dewan
Graduate Student
Penn State University
207 Hammond Building
University Park, PA 16802
814-863-7431 814-863-4745
pooja@wimpy0.PSU.EDU

** Debasish Dutta
Associate Professor
University of Michigan
2250 GG Brown Labs,
Mechanical Engineering Dept.,
Ann Arbor, MI 48109
313-936-3567 313-747-3170
dutta@engin.umich.edu

Donald Elson
Consultant (former V. P. of Technology)
Black & Decker
M/S TW070, 701 E. Joppa Road
Towson, MD 21286
410-716-3410 410-716-3653
DONALD.ELSON@BDK.COM

*On-Site Registration (Not Alphabetized)
** Registered But Did Not Attend

Shaw C. Feng
Mechanical Engineer
NIST
Meteorology Building, Room A-127
Gaithersburg, MD 20878
301-975-3551 301-258-9749
sfeng@cme.nist.gov

** Jim Fowler
NIST
Building 220, Room A-127
Gaithersburg, MD 20899
301-975-3180

Rick Franzosa
V.P., Sales & Marketing
CIMx Company
400 TechneCenter Drive
Cincinatti, OH 45150
513-248-7702 513-248-7711
rgf@cimx.com

Jon C. Freeman
Product Manager
Boeing Commercial Airplane Group
P.O. Box 3707 M/S 6M-HT
Seattle, WA 98124
206-965-6088 206-965-6766
jf3128@kgv1.bems.boeing.com

Chet Fryjoff
Product Manager
Camax Manufacturing Tech
1710 Willow Creek Circle
Eugene, OR 97487
503-687-2631 503-485-0925
chet@camax.com

** Rajit Gadh
Assistant Professor
University of Wisconsin
374 Mechanical Engineering Bldg.
1513 University Avenue
Madison, WI 53706-1572
608-268-9058 608-265-2316

Daniel M. Gaines
Research Assistant
U. of Illinois at Urbana-Champaign
2413 DCL, 1304 W. Springfield
Urbana, IL 61801
217-244-1263 217-244-8371
dmgaines@cs.uiuc.edu

Thomas Lee Galyean
Equipment Engineer
Texas Instruments, Inc.
6000 Lemmon Ave., M/S 542
Dallas, TX 75209
214-995-5070 214-995-0221
galyean@texas.dseg.ti.com

Charles Gilman
STEP Tools, Inc.
Rensselaer Technology Park
100 Jordan Road
Troy, NY 12180
518-276-2061 518-276-8471
gilman@steptools.com

Derek Grant
Project Engineer
Pratt & Whitney
400 Main Street, M/S 118-38
East Hartford, CT 06108
860-565-3844 860-565-9614
grantda@pweh.com

Satyandra K. Gupta, Ph.D.
Project Scientist
Robotics Inst., Carnegie Mellon Univ.
Center for Integrated Manufacturing
Decision Systems, 5000 Forbes Ave.
Pittsburgh, PA 15213
412-268-8780 412-268-5569
Satyandra.K.Gupta@ISL1.RI.CMU.EDU

Stephen N. Haberman
Business Systems Analyst
The Boeing Company
Boeing Commercial Airplane Group
P.O. Box 3707
Seattle, WA 98124
206-965-6091 206-965-6655
300wbmgn@kgv1.bems.boeing.com

JungHyun Han
Research Assistant
USC
Computer Science Department
Los Angeles, CA 90089
213-740-4513 213-740-7285
han@lipari.usc.edu

Paul Handel
Technical Specialist
Boeing Defense & Space Group
P.O. Box 16858, M/S P38-50
Philadelphia, PA 19142-0858
610-591-7575 610-591-4948
handelpi@putter.a1.boeing.com

Caroline Clarke Hayes
Assist. Prof. Computer Science
U. of Illinois at Urbana-Champaign
Dept. of Computer Science & Beckman
Inst.
405 North Mathews Avenue
Urbana, IL 61801
217-333-6071 217-244-8371
hayes@cs.UIUC.EDU

William J. Hlavacek
Manufacturing Engineering Planner
Boeing Commercial Airplane Group
P.O. Box 3707, M/S 6M-HJ
Seattle, WA 98124-2207
206-965-6099 206-965-6655

** Mark Horner
Boeing Helicopter
P.O. Box 16858, M/S P29-20
Philadelphia, PA 19142-0858
610-591-8913

Keith Hummel
Technical Specialist
Northrop Grumman Corp.
Grumman Data Systems
5800 International Blvd.
N. Charleston, SC 29418
803-760-3493 803-760-3780
hummel@scra.org

** David R. Hyde
2 Trap Falls Road
Shelton, CT 06484
203-929-0322 203-929-0343

Mike Iuliano
Computer Scientist
NIST
Building 220, Room A-127
Gaithersburg, MD 20899
301-975-3891 301-258-9749
iuliano@cme.nist.gov

Dr. Al Jones
Operations Research Analyst
NIST
Building 220, Room A-113
Gaithersburg, MD 20899
301-975-3554 301-258-9749
jonesa@cme.nist.gov

James A. Joninas
Project Manager
Eastman Kodak Company
901 Elmgrove Road
Rochester, NY 14653-5116
716-726-1712 716-726-7406
joninas@kodak.com

Sanjay Joshi
Associate Professor
Penn State University
207 Hammond Building
University Park, PA 16802
814-865-2108 814-863-4745
sbj@wimpy1.PSU.EDU

Robert P. Judd
Professor
Ohio University
School of Electrical & Computer Engineering
Athens, OH 45701
614-593-0106 614-593-0007
juddrp@bobcat.ent.ohiou.EDU

*On-Site Registration (Not Alphabetized)
** Registered But Did Not Attend

Raju Khanchustambham
DP Technology Corporation
1150 Avenida Acaso
Camarillo, CA 93012
805-388-6000 805-388-3085

Yong Se Kim
Assistant Professor
University of Illinois-Urbana-Champaign
Dept. of General Engineering
104 S. Mathews Avenue
Urbana, IL 61801-2996
217-333-1180 217-244-5705
yskim@uxl.cso.uiuc.edu

** Amy Knutilla
Industrial Engineer
NIST
Building 220/A-127
Gaithersburg, MD 20899
301-975-3514 301-258-9749
knutilla@cme.nist.gov

Thomas R. Kramer
Guest Researcher
NIST & Catholic University
Building 220/B-124
Gaithersburg, MD 20899
301-975-3518 301-990-9688
kramer@cme.nist.gov

Tom Laliberty
Raytheon Company
50 Apple Hill Drive
Tewskbury, MA 01876
508-858-5756 508-858-5976
Laliberty_Thomas@caemac.msd.ray.com

Abhey R. Lamba
Developer Support Analyst
Bentley Systems, Inc.
690 Pennsylvania Drive
Exton, PA 19341
610-458-2920 610-458-1056
Abhey.Lamba@bentley.com

Yuan-Shin Lee, Ph.D., P.E.
Assistant Professor
North Carolina State University
Dept. of Industrial Engineering, Box 7906
Raleigh, NC 27695-7906
919-515-7195 919-515-5281
yslee@eos.ncsu.edu

Swee Leong
Manufacturing Engineer
NIST
Building 220/A-127
Gaithersburg, MD 20899
301-975-5426 301-258-9749
leong@cme.nist.gov

*On-Site Registration (Not Alphabetized)
** Registered But Did Not Attend

Gordon Little
Research Student
University of Edinburgh
King's Buildings, Mayfield Road,
Edinburgh, EH9 3JL
SCOTLAND
44-131-650-8696
44-131-667-3677

David E. Martin
Sr. Manufacturing Consultant
ICEM Technologies
3505 Bean Creek Road
Scotts Valley, CA 95066
408-438-6641 408-438-6641

Chuck McLean
Computer Scientist
NIST
Building 220, Room A-131
Gaithersburg, MD 10899
301-975-3511 301-258-9749
mclean@cme.nist.gov

Dana S. Nau
Professor
University of Maryland
Dept. of Computer Science and Institute for Systems Research
College Park, MD 20742
301-405-2684 301-405-6707
http://www.cs.umd.edu/~nau

Donald M. Needham
University of Connecticut
Dept.of Computer Science & Eng.,
170 Davis Road
Storrs, CT 06268
860-429-2545 860-486-4817
needham@eng2.uconn.edu

Erroll M. Palmer
Production Control Dept. Head
Naval Ordnance Station Louisville
Code 90A4, NAVSURFWARCEN ORDSTA
5403 Southside Dr.
Louisville, KY 40214-5001
502-364-6592 502-364-6415
ERROLL_P@LOUIS.NOSL.SEA06.NAVY.MIL

Charles Parks
Professor & Chair, Industrial and Manufacturing Systems Engineering
Ohio University
268 Stocker Center
Athens, OH 45701
614-593-1546 614-593-0778
cparks@bobcat.ent.ohiou.edu

Jim Patterson
Technical Specialist
Boeing Defense & Space Group
P.O. Box 16858, M/S P38-50
Philadelphia, PA 19104-0858
610-591-4345 610-591-4948
pattersonJJ@putter.a1.boeing.com

Dr. Arati Prabhakar
Director
NIST
Administration Building, Room 1134
Gaithersburg, MD 20899
301-975-2300 301-869-8972
director@nist.gov

Luis C. Rabelo
Associate Professor
Ohio University
Room 274, Stocker Center
Athens, OH 45701
614-593-1542 614-593-0778
rabelo@bobcat.ent.ohiou.edu

Steven Ray
Mechanical Engineer
NIST
Building 220, Room !-149
Gaithersburg, MD 20899
301-975-3524 301-258-9749
ray@cme.nist.gov

Dr. William Regli
NRC Research Associate
NIST
Building 220, Room A-127
Gaithersburg, MD 20899
301-975-4427 301-963-6556
regli@cme.nist.gov

Frank Riddick
Computer Scientist
NIST
Building 220, Room A149
Gaithersburg, MD 20899
301-975-3524 301-258-9749
riddick@cme.nist.gov

Denny Rock
The Boeing Company
P.O. Box 16858, M/S P28-24
Philadelphia, PA 19142-0858
610-591-3848
rockd@putter.a1.boeing.com

Charles F. Sack, Jr.
Sr. Research Analyst
United Technologies
Pratt & Whitney Aircraft, MS 118-38
400 Main Street
East Hartford, CT 06108
860-565-3222 860-565-9614
sackcf@pweh.com

Ezat T. Sanii
Assoc. Professor of Industrial Engineering &
Assoc. Director for Academic Affairs
IMSE Institute
NC State University
Dept. of Industrial Engineering,
Campus Box 7906, 328 Riddick Lab
Raleigh, NC 27695-7906
919-515-7196 919-515-5281
sanii@eos.ncsu.edu

Dr. Linda C. Schmidt
Assistant Professor
University of Maryland
Dept. of Mechanical Engineering
College Park, MD 20742-3035
301-405-0417 301-314-9477
lschmidt@eng.umd.edu

David E. Schmitz
Professor of Engineering Management
Defense Systems Management College
9820 Belvoir Road, ATTN: FDMM
Ft. Belvoir, VA 22060-5565
703-805-3765 703-805-3721
schmitz@dsmc.dsm.mil

J. MacGregor Smith
Professor
University of Massachusetts
Dept. of Mechanical & Industrial
Engineering Box 32210
Amherst, MA 01003-2210
413-545-4542 413-545-1027
JMSMITH@ecs.umass.edu

Michael C. Smith
Senior Scientist
SAIC
1710 Goodridge Drive, M/S 1-7-6
McLean, VA 22102
703-827-4772 703-893-2187
michael.c.smith@cpmx.saic.com

Dusan N. Sormaz
Assistant Professor
Ohio University
280 Stocker Center
Athens, OH 45701-2979
614-593-1548 614-593-0778
sormaz@bobcat.ent.ohiou.edu

Dr. Ram D. Sriram
Group Leader, Engineering Design
Technologies
NIST Manufacturing Systems Integration
Building, Room A127
Gaithersburg, MD 20899-0001
301-975-3507 301-258-9749
sriram@cme.nist.gov

Simon Szykman
Mechanical Engineer
NIST
Building 304, Room 12
Gaithersburg, MD 20899
301-975-4466 301-926-3842
szykman@cme.nist.gov

Dominick Terra
Senior Applications Engineer
ADRA Systems, Inc.
301 Lindenwood Drive, Suite 1
Malvern, PA 19355
610-640-3122 610-640-3105
terra@adra.com

*On-Site Registration (Not Alphabetized)
** Registered But Did Not Attend

John M. Usher
Associate Professor
Mississippi State University
Dept. of Industrial Engineering
P.O. Box 9542/125 McCain Bldg.
Miss. State, MS 39762
601-325-7624 601-325-7618

Yu (Michael) Wang
Assistant Professor
University of Maryland
Dept. of Mechanical Engineering, Bldg. 2181
College Park, MD 20742-3035
301-405-0416 301-314-9477
yuwang@eng.umd.edu

Richard A. Wysk
Professor
Penn State University
207 Hammond Building
University Park, PA 16802
814-863-1001 814-863-4745
rwysk@wimpy1.PSU.EDU

Derek Michael Yip-Hoi
Doctoral Student
University of Michigan
Dept. of Mechanical Engineering
2289 G.G. Brown Laboratory
Ann Arbor, MI 48109-2125
313-763-4056 313-747-3170
yiphoi@engin.UMICH.EDU

*Irvin M. Bohr
Manufacturing Support Manager
Black & Decker
U.S. Power Tools Group, MS 150
701 East Joppa Road
Towson, MD 21286
410-716-2808 410-716-32453

*Greg Carroll
Syntek
4301 North Fairfax Drive
Arlington, VA 22203
702-525-3403 703-525-0833

*Michael R. Duffey
George Washington University
2130 H. Street, NW
Washington, DC 20817
202-994-7173 202-994-4606
duffey@seas.gwu.edu

*Stephen Klomparens
Vice President
Syntek
4301 North Fairfax Drive
Arlington, VA 22203
702-525-3403 703-525-0833
shklomp@interramp.com

*On-Site Registration (Not Alphabetized)
** Registered But Did Not Attend

* Zhi-Kui Ling
IPA
Michigan Tech
Mechhanical Engineering Department
Houghton, MI 49931
906-487-2620 906-487-2822
ling@mtu.edu

* Avouk Loreau
Guest Researcher
NIST
Gaithersburg, MD 20899
301-975-5446
Avoukloreau@nist.gov

* Kevin Lyons
Mechanical Engineer
NIST
Building 304, Room 12
Gaithersburg, MD 20899
301-975-6550
klyons@cme.nist.gov

* Prasad Mandava
University of Maryland
6108 Breezewood Drive, #204
Greenbelt, MD 20770
301-474-0889
mandava@cme.nist.gov

* Dr. Venkat Rajan
Guest Researcher
NIST
Building 304, Room 12
Gaithersburg, MD 20899
301-975-6543
rajan@cme.nist.gov

* Craig Schlenoff
Mechanical Engineer
NIST
Building 220, Room A127
Gaithersburg, MD 20899
301-975-6536 301-258-9749
schlenof@cme.nist.gov

* Raj Sreerangam
Guest Researcher
NIST
Building 304, Room 12
Gaithersburg, MD 20899
301-975-6543
sraj@cme.nist.gov

* Bob Tuttle
Research Engineer
Heriot-Watt University
Department of Mechnical & Chemical
Engineering, Riccarton
Edinburgh, SCOTLAND EH14 4AS
44131447514 Ext. 4343
b.tuttle@hw.ac.uk

*On-Site Registration (Not Alphabetized)
** Registered But Did Not Attend

Appendix B. Workshop Agenda

NIST Manufacturing Process Planning Workshop and CAME Forum Workshop

June 10-11, 1996
8:00 AM to 5:00 PM
Grand Ballroom
Gaithersburg Marriott Washington Center
9751 Washingtonian Boulevard
Gaithersburg, MD 20878

Agenda - Monday, June 10

Continental Breakfast		8:00-8:30 AM
Welcome and Introduction	Dr. Arati Prabhakar	8:30-8:45 AM
Workshop Purpose and Objectives	Dr. Bill Regli	8:45-9:00 AM
CAME Forum Update	Mr. Chuck McLean	9:00-9:30 AM
Manufacturing Process Planning Update	Dr. Steven Ray	9:30-10:00 AM
Break		10:00-10:15 AM
Breakout Session I (Futures -general) • Research: What are the new technologies that will facilitate manufacturing integration and process planning? What are the major technical hurdles and research challenges? • Development/Vendor: What do you see as the next generation tools being used? What are the key enabling technologies? • Users: What are the critical information technology needs/challenges that affect competitiveness? What are the elements of the business case that will lead to their adoption?		10:15-11:45 AM
Report Out I	Spokespersons	11:45-12:30 PM
Lunch		12:30-1:00 PM
Keynote Address	Dr. David Bourne Carnegie-Mellon U.	1:00-1:45 PM
Questions and Discussion		1:45-2:00 PM
Breakout Session II (Futures - specific) • Topic 1: What will become the dominant information technology paradigm for manufacturing engineering and process planning? • Topic 2: How will manufacturing integration and process planning technologies effect the next business "culture" (and vice-versa)? • Topic 3: What manufacturing domains beyond machining are attractive targets for integration and process planning technologies?		2:00-3:30 PM
Break		3:30-3:45 PM
Report Out II	Spokespersons	3:45-4:30 PM
Plenary Discussion	Facilitator	4:30-5:00 PM
Adjourn		5:00 PM

NIST Manufacturing Process Planning Workshop and CAME Forum Workshop

June 10-11, 1996
8:00 AM to 4:45 PM
Grand Ballroom
Gaithersburg Marriott Washington Center
9751 Washingtonian Boulevard
Gaithersburg, MD 20878

Agenda - Tuesday, June 11

Continental Breakfast		8:00-8:30 AM
Workshop Review	Facilitator	8:30-8:45 AM
Keynote	Pete Buca Parker Hannifin Corp.	8:45-9:30 AM
Questions and Discussion		9:30-9:45 AM
Breakout Session III (Technology focus -- specific topics to be determined based on participants' interests)	Facilitator	9:45-10:45 AM
Break		10:45-11:00 AM
Report Out III	Spokespersons	11:00-11:30 AM
Keynote	Peter Brooks Bentley Systems, Inc.	11:30-12:15 PM
Lunch		12:15-1:00 PM
Breakout Session IV ("mixed" membership groups) • Research: What is the appropriate role of the research community in addressing manufacturing integration and process planning needs? • Development/Vendor: What is the appropriate role of vendors in addressing manufacturing integration and process planning needs? • Users: What is the appropriate role of users in addressing manufacturing integration and process planning needs? • Gov't/Stds Organizations: What is the appropriate role of government and standards organizations in addressing manufacturing integration and process planning needs?	Facilitator	1:00-2:30 PM
Report Out IV		2:30-3:15 PM
Break		3:15-3:30 PM
Moderated Panel Session	Spokespersons (III & IV)	3:30-4:15 PM
Workshop Wrap-up	Facilitator	4:15-4:30 PM
Adjourn		4:30 PM

Appendix C. Program Updates and Keynote Presentations

• Computer-Aided Manufacturing Engineering (CAME) Program Overview	Chuck McLean
• 1996 Process Planning Workshop and CAME Forum	Steven Ray
• Process Planning: Capturing the Imagination	David Bourne
• Mechanical Space	Peter Brooks
• Business and Operations Requirements	Pete Buca

Appendix C1

Computer-Aided Manufacturing Engineering (CAME) Program Overview

Computer-Aided Manufacturing Engineering Program Overview

Chuck McLean

Group Leader

Manufacturing Systems Engineering

NIST

10 June 1996

Topics

- **Background**
  - Mission and objectives
  - Computer-Aided Manufacturing Engr. Program
- **Manufacturing Engineering Tool Kit (METK)**
- **Other projects underway**
- **CAME Forum**

Mission and Objectives

To perform research and development in technology and standards for creating integrated engineering tool kit environments

- Identification and evaluation of new tools, methods, and algorithms for rapidly translating product design data into manufacturing plans, process designs, and system specifications

- Modeling, evaluation, and validation of solutions using simulation and analysis systems

- Development of information/functional models, databases, architectures, and interface specifications to support tool integration

- Establishment of a testbed and repository of models and data for evaluating integration solutions, conducting conformance testing, etc.

Industry Needs

- **Workshop in 1993 identified two greatest industry needs**
  - engineering tool integration
  - data validation (ability to produce first part right)
- **CAME Forum meetings in 1995 identified:**
  - Candidate machine shop processes
  - Test parts
  - Sources of data errors

CAME Focus

The CAME Program is placing an emphasis on providing:

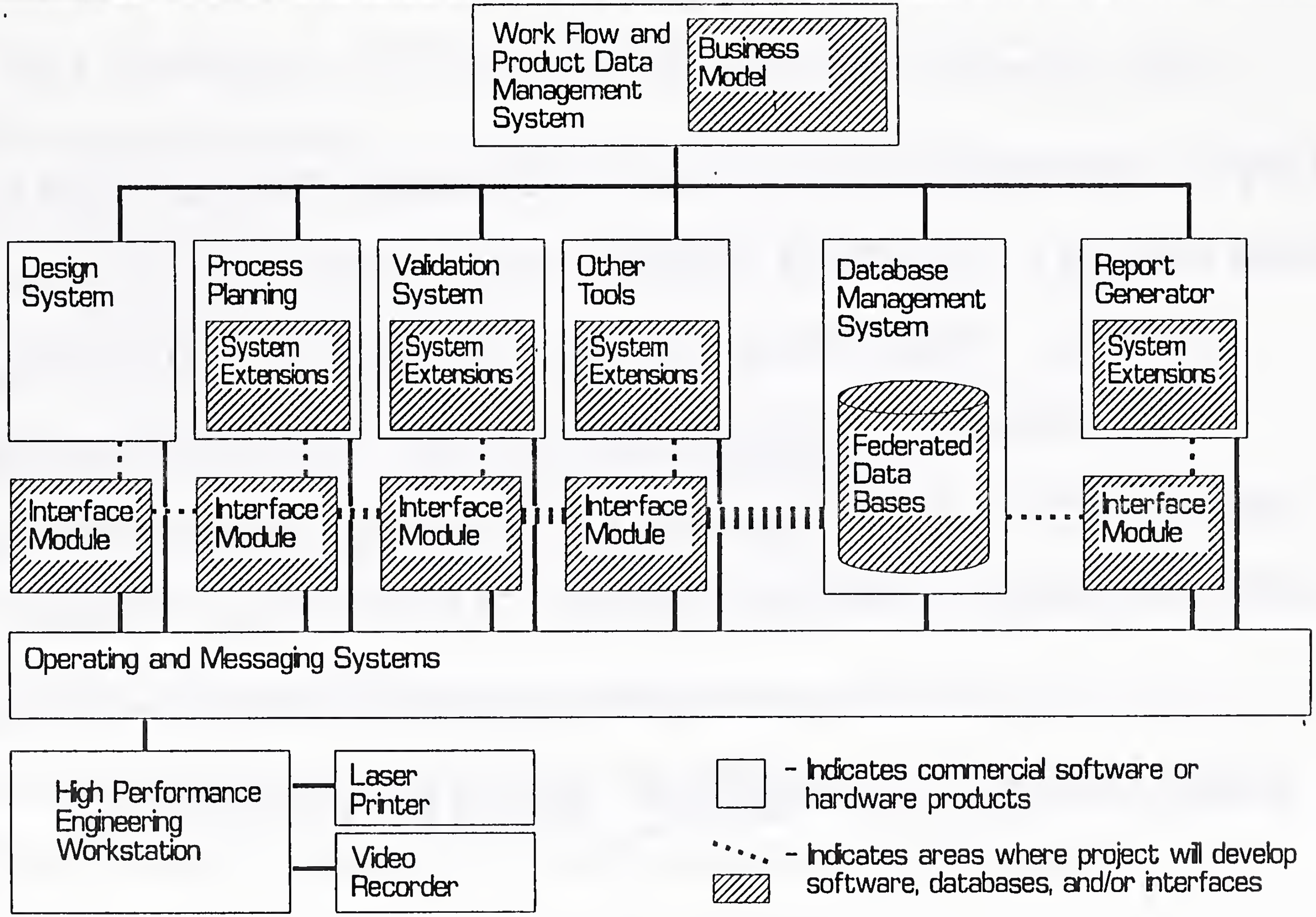
- *an integrated framework*
- *methods and techniques*
- *common databases, and*
- *interface standards*

which are needed to apply engineering methods to the design and implementation of manufacturing systems, processes, and equipment using commercial off-the-shelf software.

Mfg. Engineering Tool Kit (METK)

- **Construct an integrated tool kit and databases for planning the manufacture of machined parts**
- **Required functionality:**
  - work flow and product/process data management
  - design data entry
  - process planning (routings and operations)
  - APT program generation and NC post-processing
  - resource data management (tools, fixtures, etc.)
  - manufacturing data package validation

METK System Concept



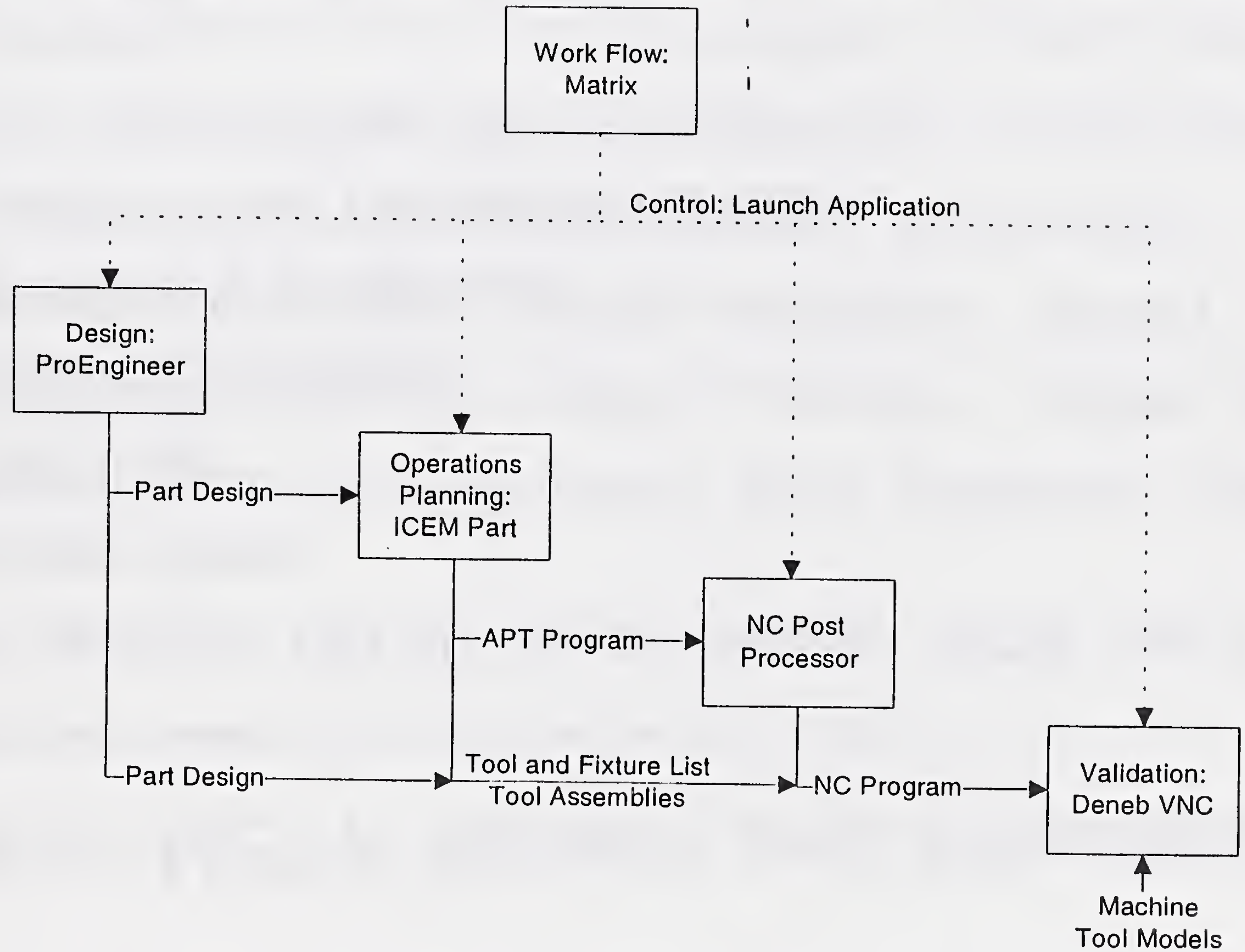
Current METK Software Modules

- Design: Parametric Technologies - ProEngineer
- Operations Planning: Technomatix - ICEM Part
- NC Validation: Deneb Robotics - Virtual NC
- Routing Validation: Deneb Robotics - Quest
- Federated Database: Object Design - Object Store
- Product Data Management: Adra Systems - Matrix

Key METK Models and Interfaces

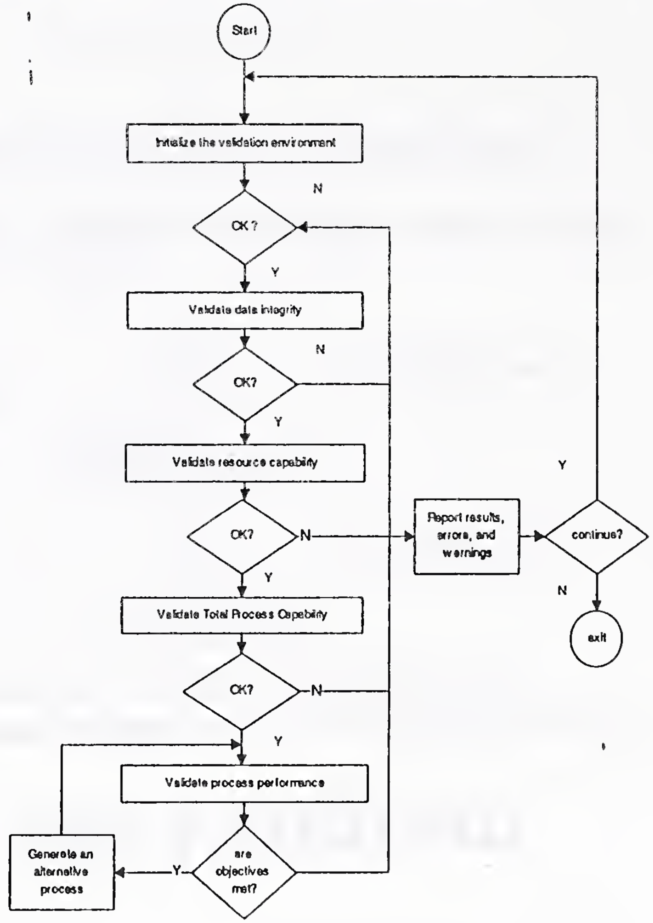
- **Part designs (STEP, ProE, Deneb, ACIS, etc.)**
- **Process plans**
  - Routings
  - Operation sheets
- **APT and NC programs**
- **Manufacturing resource models**
  - Tool assemblies, fixtures, etc.
  - Machines
- **Work element framework**
- **Engineering business model**
- **Document check in / check out protocol**

Current METK Logical Data Flow



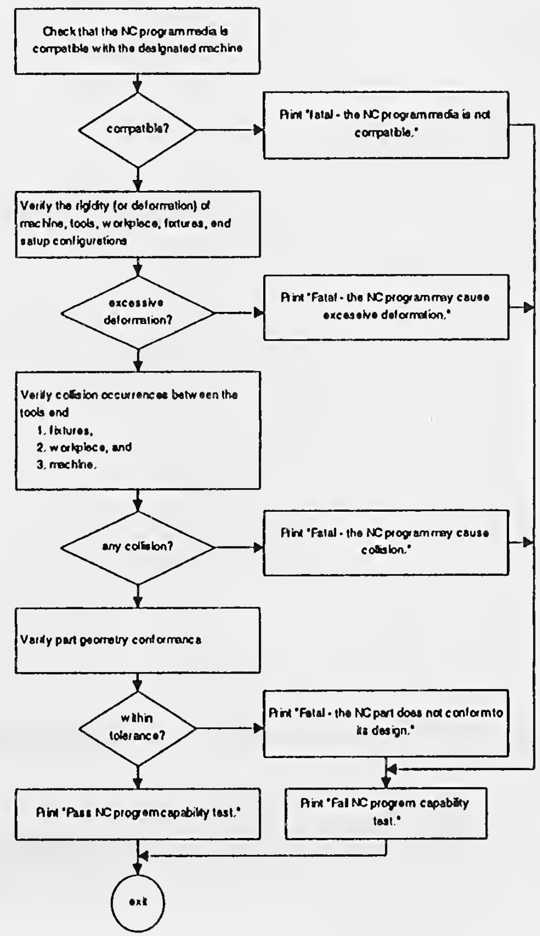
Data Validation Methodology

- A methodology to help ensure that first part is produced correctly
- Methodology addresses:
  - *Data Integrity*
  - *Resource Capability*
  - *Total Process Capability*
  - *Process Performance*
- Can be implemented manually or automatically



Validate TPC for NC Program

- **Ensure that the NC program is correct**
  - Correct media
  - Rigidity of setup, tools, etc.
  - No collisions
  - Part geometry produced
- **Validation code is being implemented as work element executables in simulated production facility**



Process Plan Interpreter

- **Runs in Deneb VNC**
- **Executes a workstation level process plan to perform validation functions and manipulate the simulation environment**
- **Invokes work element code**
- **Currently handles:**
  - initialization of simulation
  - setup of tool magazine, fixture, and workpiece
  - NC program execution

METK Contributors

- **Vendors and Industrial Users**
  - Deneb Robotics, Technomatix, Adra Systems
  - Boeing, Litton AMECOM, McDonnell-Douglas, Black and Decker, Texas Instruments
- **Researchers**
  - Ohio University: Judd
  - Florida International University: Chen
- **Government**
  - NIST: Iuliano, Leong, Riddick, Frechette, Feng, Jones, Barkmeyer, McLean
  - Naval Ordnance Station, Louisville: Palmer
  - Army Rock Island Arsenal, Army TACOM

Other Projects Underway

- Scheduling and Shop Floor Data Collection
- SIMA Production and Product Data Management
- NAMT Machine Tool Modeling

CAME Forum

Organizing CAME Forum as a consortium which will address engineering tool integration and mfg. data validation issues including:

- Identification and documentation of industry requirements
- Definition of models, methods, and interface specifications
- Development of pilot tool kit environments
- Testing of tool kits with real data at industry sites

For further information, please contact:

Mr. Swee Leong

(301) 975 - 5426

leong@cme.nist.gov

Appendix C2

1996 Process Planning Workshop and CAME Forum

NIST

1996 Process Planning Workshop and CAME Forum

Steven Ray

Manufacturing Engineering Laboratory

NIST

June 10-11, 1996

NIST

Welcome!

- Process Planning Workshop series
- Objectives
- Observations on the state of the practice, state of the art

NIST

Process Planning Workshop series

#1: Texas A&M University, 1991
  » Primarily university researchers

#2: NIST, 1992
  » Primarily university researchers

#3: NIST, 1993
  » Industrial users and vendors

#4: Here, 1996
  » Industry, vendors and university

NIST

Workshop #1

- Reinforce a group identity for the process planning community
- Agreement on high-level infrastructure for process planning research systems
- Creation of a forum for exchange of process planning information
- Call for a manufacturing resource model

NIST

Workshop #2

- Define need for common data models & access mechanisms
- Identify architectural and data requirements
- To better position process planning research with respect to industry relevance

NIST

Workshop #3

- Industrial needs
- Trends in industrial practice
- Trends in system capabilities
- Challenges and obstacles
- Prepare feedback to the research community

NIST

Feedback from Workshop #3

- The need for information and communication standards
- Requirements for process planning systems
- Business and cultural implications of integrating process planning systems

NIST

#3 - Standards Needs

- Manufacturing Resource Models
- Features
- Architecture
- Knowledge representation

NIST

#3 - System Requirements

- Hybrid approach, incorporating variant, interactive and generative characteristics
- Support for legacy plans

NIST

#3 - Business & Culture

- Challenge of how to address cost of new technologies
- Information overload for user
- Management restructuring & education needed (buy-in)

NIST

Workshop #4

- Three perspectives:
  - Academia
  - Industry
  - Vendor
- Future projections, needs, opportunities
- Marching orders for each of us

Appendix C3

Process Planning: Capturing the Imagination

Process Planning: Capturing the Imagination

David Bourne
Senior Scientist
Carnegie Mellon University
Robotics Institute

Overview

- Video (3 min): Where did we come from?
- Comments about general process planning
- FOCUS: Planning for sheet metal bending
- Is operations-planning a good enabling technology
- Video (3 min): Where are we?

What are some of the research issues in/and around planning?

Process Planning

Every Part Is A Boundary Part

- **Process Planning (Process Selection)**
- **Operations Planning (Single Machine)**

Variant:	Reasoning from similar plans
Generative:	Reasoning from first principles

The Tool is Too Small

The Flange is Too Big

The Robot Can't Reach

The Gripper is Too Wide

The Tool Interferes with Part

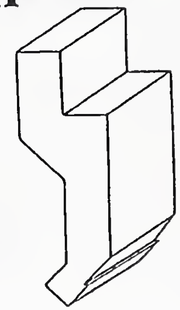
There is No Place to Gage

The Material is The Wrong Type for Available Tools

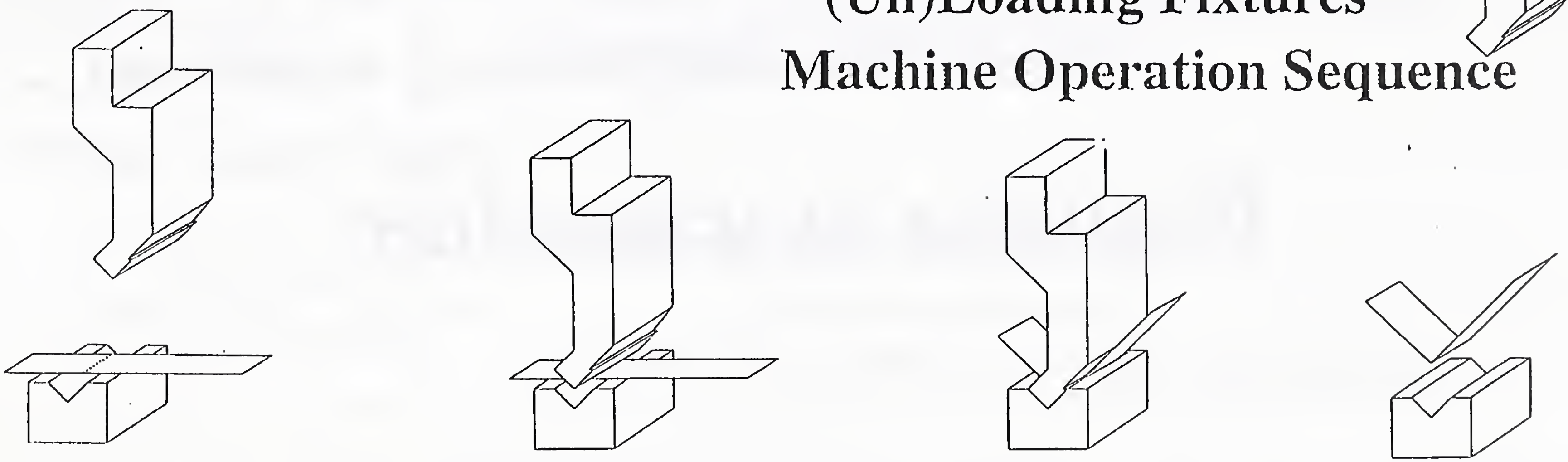
Let's Focus: Sheet Metal Air-Bending

Machine Configuration/Setup

- Robot (Choose Grippers)
- Tools (Choose Punches, Dies, Die Holders, Punch Holders)
- Backgage Contacts
- (Un)Loading Fixtures



Machine Operation Sequence



Approach to Planning

- **Generative Process Planning (ABE)**

Function: Build plan step-by-step from first principles

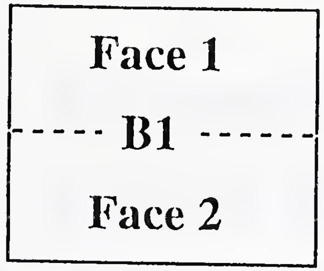
Idea: It is possible to derive each step of the plan automatically

Advantages: It can be fully automatic and doesn't require similarity op.
Can be generalized to machine and tool variations

Disadvantages: Requires extensive models of process
Problem complexity can be overwhelming

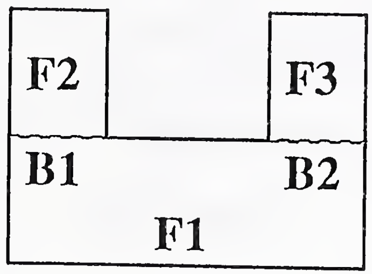
Getting The Principles Right

For example, how is a bending operation specified?



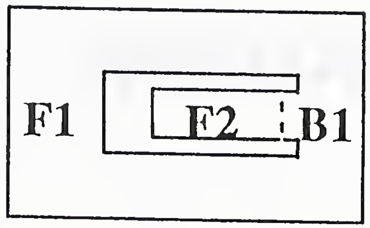
either (B1 Face1) or (B1 Face2)
where Face-n is held by the robot and
is outside of the machine

What about colinear bends?



either ((B1 B2) F1) or (B2 B1) F2)
where F-n ~~is held by the robot and~~
is outside of the machine

What about a tab?

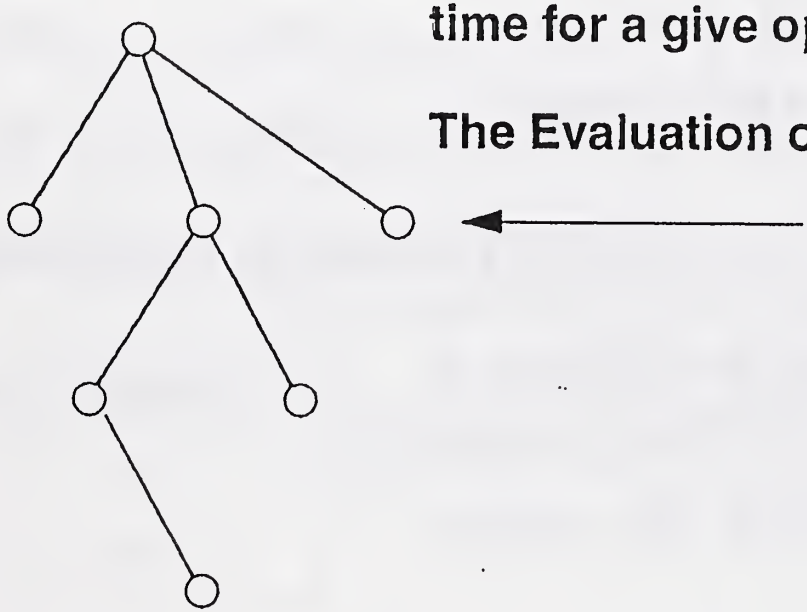


either (B1 F1) or (B1 F2)
where a point near B-k is in F-n and is outside of machine

Searching for Near Optimal Plan

We Are Using an A* Search to Find
Best Plans:

Flat Part



Final 3D Part

Costs are based on estimated elasped time for a give operation..

The Evaluation of one Node Can Take 5sec. to 2 min.

At Each Level Consider:
(1) Bends to be done
(2) Robot regrasping operation

At Each Node Calculate Cost:
(1) Of that node (K)
(2) Estimated Cost to Goal (H)
(3) Preliminary Plan for That Node

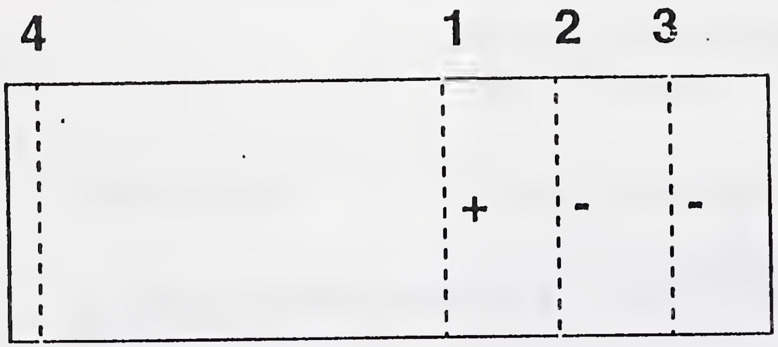
Expand the Cheapest Node Next:
Sum of K's + H

Big Problem: Finding a solution when objective functions mismatch.
Good Robot Grasping Plan requires Special Expensive Special Bending Tools
Good Tooling Plan make Grasping Impossible

Broad Based
In-Planner Research Issues

- Recognizing the “right” features
- Feature interactions
- Sharing features between process domains (e.g., tooling’s features with grasping)
- Towards machine independent planning
- Tolerance sensitive planning

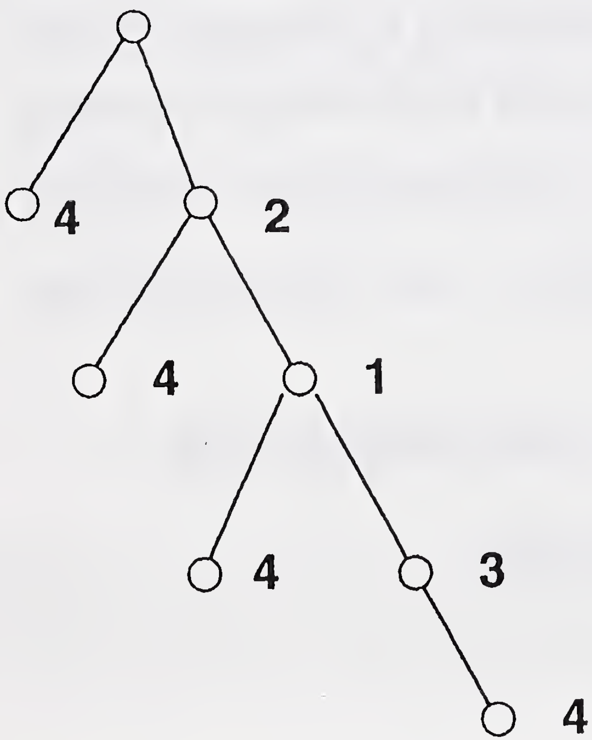
Turning Features into Constraints



Channel Feature

(* 2 * 1* 3 *)

Constraint

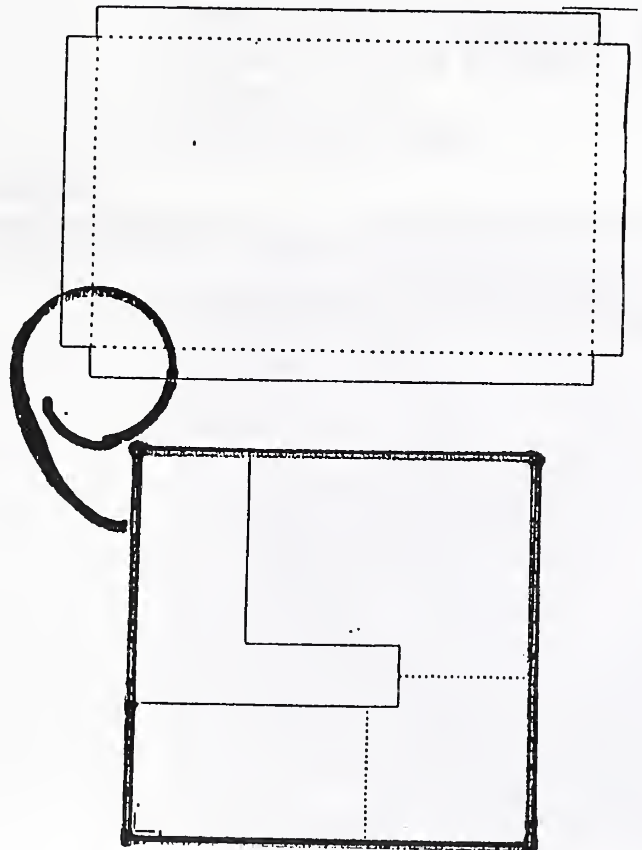


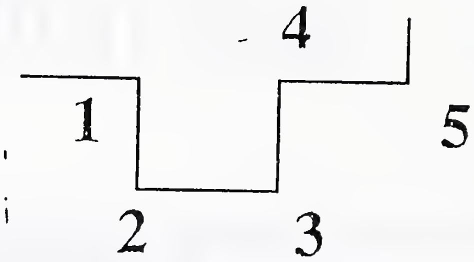
Before Search Collect All Constraints and Check Consistency

Only Expand Nodes Consistent with All Constraints.

If Impossible Situations are Eliminated Before Search then A* can Quickly Identify Solution.

Some Bending Feature Types





(1 2 3 4) -> HAT

(1 2 3) -> Channel

(2 3 4) -> Channel

(1 2) -> Z

(3 4) -> Z

(4 5) -> Z

<u>Micro Features</u>

Bend Order Depends on Physical Bending Characteristics (Springback)

<u>Macro Features</u>

Bend Order Depends on Holding Side/Dimensions/ Adjacent Features

What A Partial Plan Looks Like

Commands to Robot and Backgage to Put Part Into Position

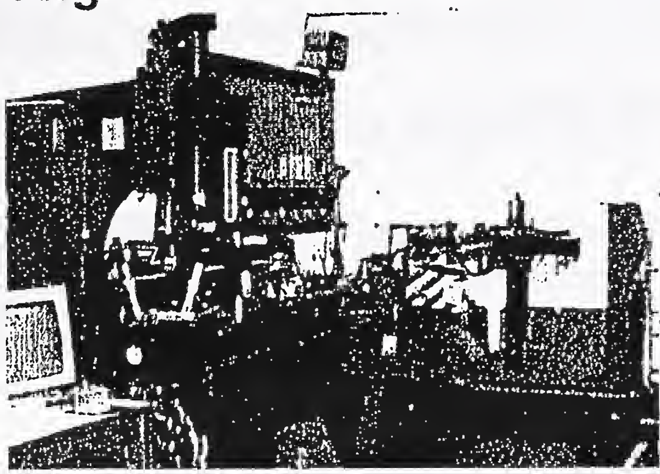
```
(PUT
        ((TYPE PRESSBRAKE)
         (ROBOT_ABS_MOVE ((899.50 -510.00 488.50 0.00 -90.00) (899.50 -517.50 488.50 0.00 0.00) ...
         (ROBOT_ZGAGE (88.00 250.00))
         (MEMORIZE_PRELOAD_POINT (-200.50 -398.00 103.50 0.00 0.00))
         (BGAGE_ABS_MOVE ((-58.50 88.00 -342.50 88.00 50.00)))
         (ROBOT_REL_MOVE ((0.00 90.00 0.00 0.00 0.00)))
         (ROBOT_ABS_MOVE ((-200.50 -308.00 83.50 0.00 0.00)))
         (ROBOT_YGAGE (-298.00 -278.00 -303.00 -58.50 -342.50 50.00))
         (BGAGE_ABS_MOVE ((-58.50 88.00 -342.50 88.00 58.00) (-12.50 88.00 -353.75 88.00 58.00)))
         (ROBOT_REL_MOVE ((20.00 0.00 0.00 0.00 0.00)))
         (BGAGE_ABS_MOVE ((-12.50 88.00 -353.75 88.00 46.00)))
         (ROBOT_XGAGE (-200.50 -220.50 -195.50))
         (BGAGE_ABS_MOVE ((-12.50 88.00 -361.75 88.00 46.00) (-12.50 88.00 -361.75 88.00 58.00) ...
         (ROBOT_REL_MOVE ((0.00 -5.00 0.00 0.00 0.00)))
         (MEMORIZE_LOAD_POINT (-200.50 -298.00 83.50 0.00 0.00))
         (BGAGE_ABS_MOVE ((-58.50 88.00 -342.50 88.00 50.00)))
         (ROBOT_YGAGE (-298.00 -278.00 -303.00 -58.50 -342.50 50.00))
         (MEMORIZE_BEND_POINT (-200.50 -298.00 83.50 0.00 0.00)) ) )
```

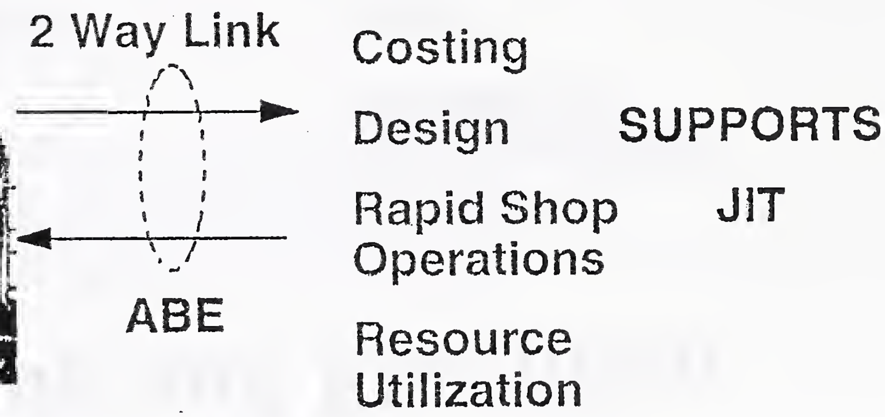
Commands to Pressbrake to Bend Part

```
(BEND
        ((TYPE FOLLOW)
         (BEND (1 1))
         (BEND_ANGLE 90.00)
         (MATERIAL_THICKNESS 1.22)
         (PRESS_TRAVEL 2.57)
         (FOLLOWING_SPEED 0)
         (BGAGE_ABS_MOVE ((-58.50 88.00 -342.50 88.00 66.00))) ) )
```

The Information Gap

- The largest gap in information in today's factory is at the boundary between the machine tool and engineering and design.





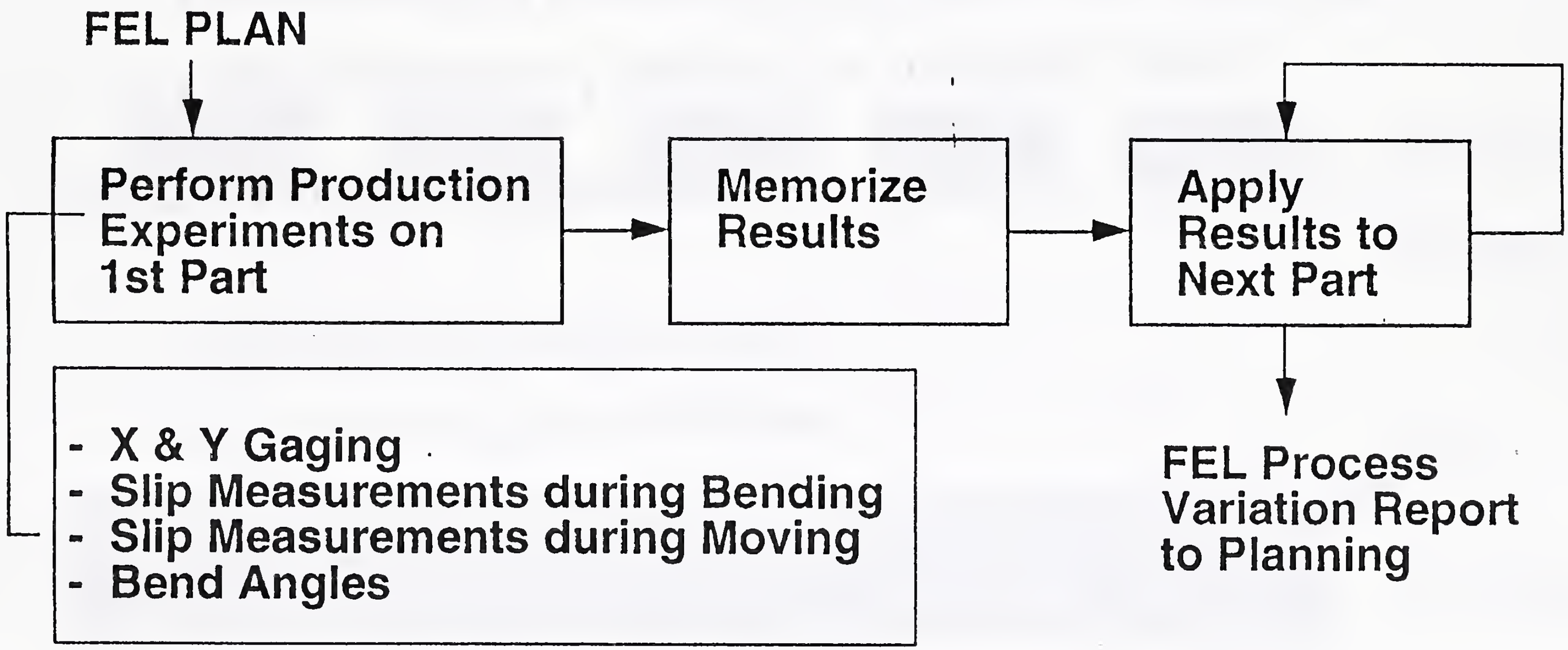
- The solution is to automatically plan part production on the machines and feedback results to engineering (software) for redesign and/or plan optimization.

Timing Breakdown for Planning, Setup and Execution

Operation	Seconds
Auto Bend Sequence Planning Time	2:30
Human Following Plan / Setup Tooling	9:10
Human Following Plan / Setup L/UL	2:50
Auto Part Production	5:47
Total Time	19:17

Flexibility
Speed
Quality

The Advantage of Feedback



Production Time Improvement: Almost Factor of 2 (e.g. 5:40 to 3:05)

Let's Assume:
The Process Planner Works!

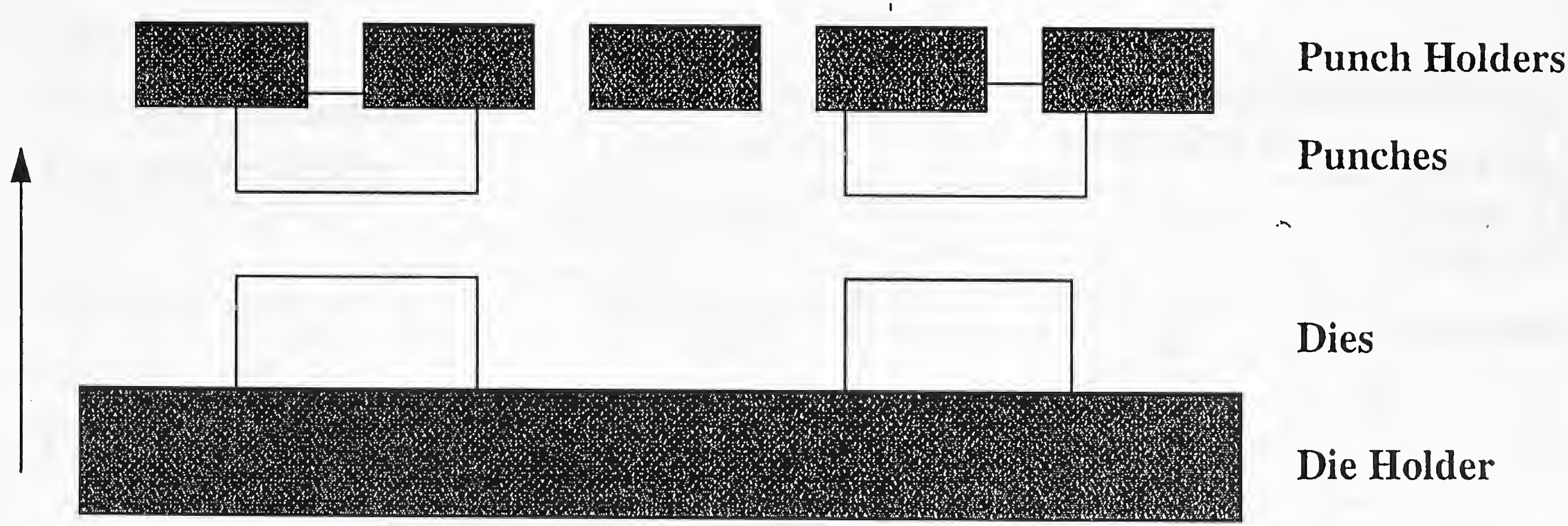
Delivery on Old Promises

- Cost effective one-off (custom) manufacturing
- JIT factory floor support
- Automated design critics

Delivery on New Promises!

- Optimization of setups for multiple parts
- Decomposing products to manufacturable parts
- Develop model of competitor: Design for ~Manufacture

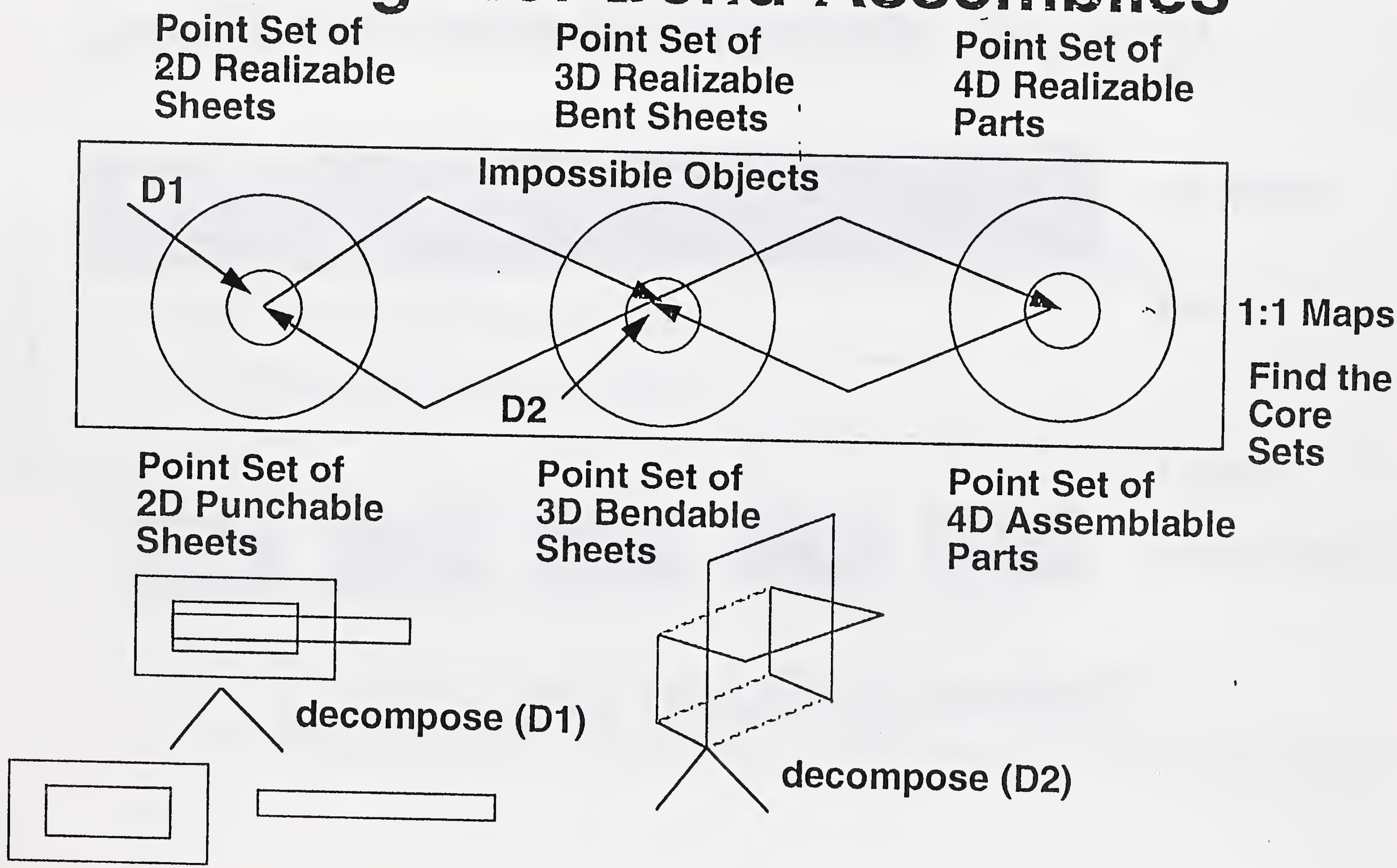
Multi-Part Setup Planning



What parts can you make on this setup?

How do you setup the machine for multiple parts?

Mathematics of Concurrent Design for Bend-Assemblies



Technology +
The Competitive Edge

Intelligent Product Decomposition

25 Parts * P(t)
+
3 Setups * S(t)

Company C $

Multi-Part Setup Planing

50 Parts * P(t)
+
5 Setups * S(t)

Company B $

AS-IS

50 Different Parts * Production(time)
+
50 Setups * Setup(time)

Company A $

Small Batch --> Increase Technology
Large Batch --> Decrease Time

Appendix C4

Mechanical Space

MechanicalSpace

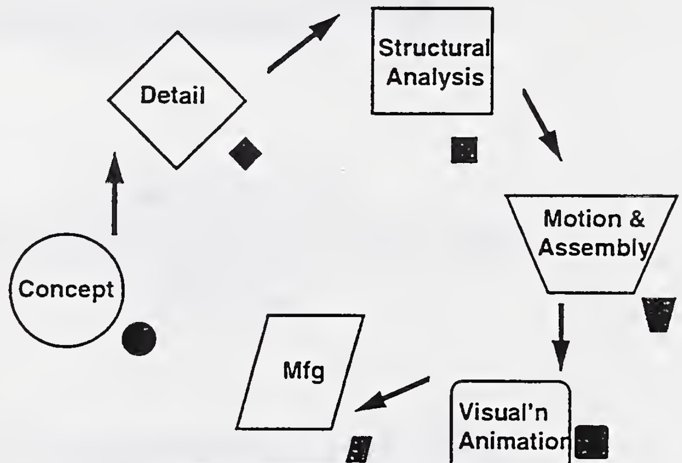
Peter Brooks
Director, Mechanical Products
Bentley

NIST Process Planning/CAME
Conference

Bentley in Mechanical Engineering

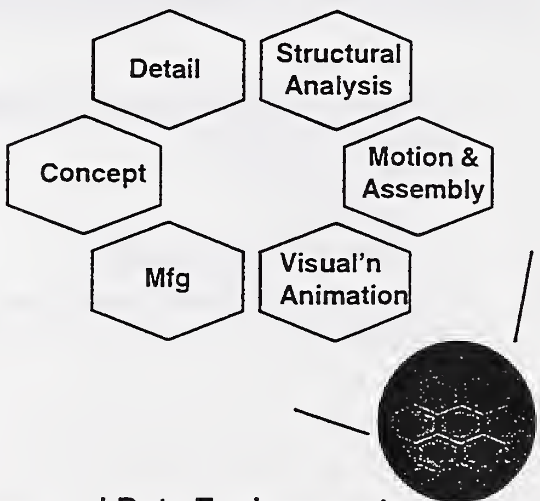
- Daratech 1996 projection: #11 CAD/CAM/CAE company worldwide
- MCAD in 1995
  - $14 Million
  - 33,000 MCAD users worldwide
- MicroStation product growth rate: Highest in the industry

Translation-based Workflow



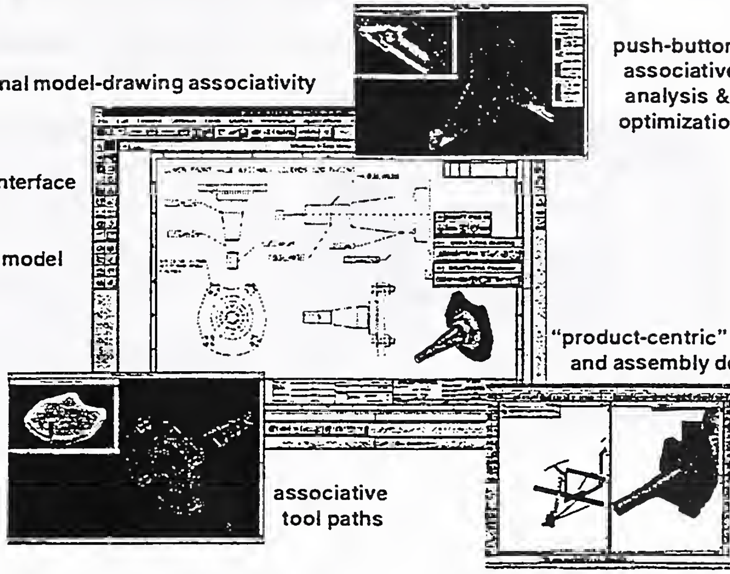
Separate User and Data Environments
Lower Quality and Productivity

Single Engineering Model Workflow



Single User and Data Environment
Higher Quality and Productivity

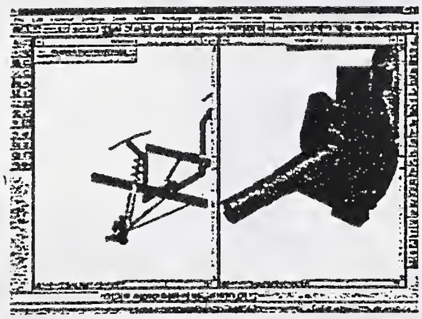
Single Engineering Model



MechanicalSpace Products

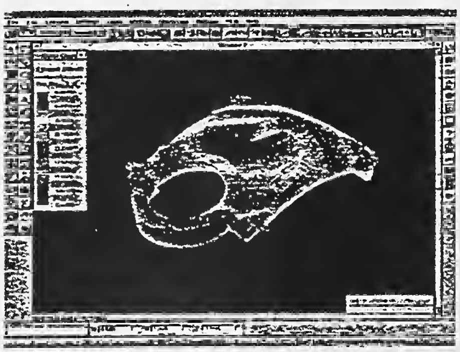
- MicroStation Modeler by Bentley
- COSMOS/M Designer II by Structural Research & Analysis
- ADAMS/MS Motion & Mechanisms by Mechanical Dynamics
- DRAFT-PAK Mechanical by Baystate Technologies
- ESPRIT/MS PowerFold, PowerLink & CAM by D.P. Technology

MicroStation Modeler



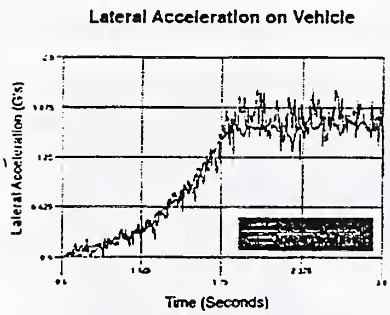
- Integrated 3D assembly, solid, surface, wireframe modeling
- Hybrid CSG and B-Rep
- Parametric, variational and feature-based design
- Associative mechanical drafting
- DOS, Windows, UNIX
- Open environment: STEP, IGES, ACIS, OLE, DWG, DGN, CGM, MDL

COSMOS/M DESIGNER II



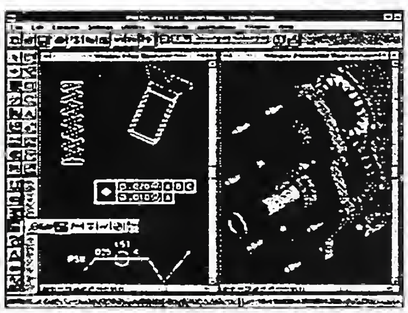
- Integrated design and analysis
- Automatic meshing
- Associative loads
- COSMOS/M, ANSYS, NASTRAN solvers
- Stress, dynamics, thermal, and fluids
- Integrated results visualization
- Structural Research distribution

ADAMS/MS Motion and ADAMS/MS Mechanisms



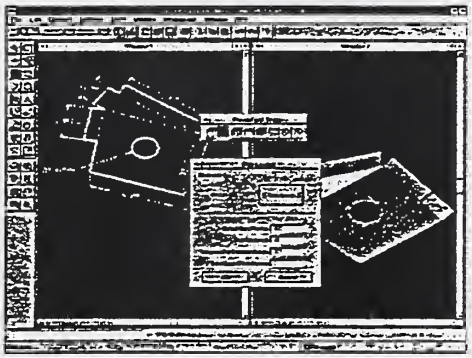
- Integrated design and analysis
- Motion
  - Check motion paths
  - Locate lock-up position, detect part interferences
  - Create assembly motion
- Mechanisms
  - Motion
  - Calculate joint reaction forces
- Bentley distribution worldwide

DRAFT-PAK Mechanical



- Mechanical Standard Parts
  - Features, fasteners, mechanical elements
  - 2D, 3D wireframe, and 3D solid parametrics
- Dimensioning & Detailing
  - Automated GD&T
  - Automatic feature labeling
  - Symbols and notes
  - ISO, ANSI, JIS, DIN, KS standards
- Bentley distribution worldwide

ESPRIT/MS PowerFold



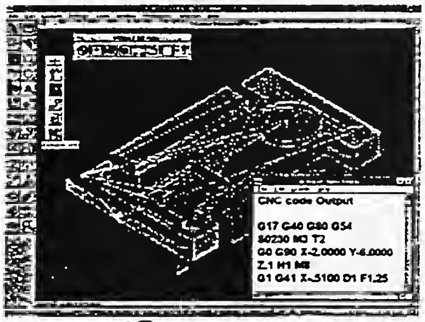
- Sheet metal design
- Forming simulation
- Materials database
- Automated unfolding
- Recognizes weld and bend lines
- Automatic computation of bend allowance
- Bentley distribution worldwide

ESPRIT/MS PowerLink

- MDL application to export MicroStation design database to ESPRIT CAM database
- First step in complete MDL integration
- Shipping now
- DP Technology distribution

ESPRIT/MS

New Product Announcement!



- Single Engineering Model integration
- Milling
- Turning
- Wire EDM
- Sheet Metal
- DP Technology distribution

MechanicalSpace

- **Through the innovative "single engineering model" approach which integrates MicroStation Modeler, COSMOS/M, ADAMS, ESPRIT/MS and other products, Bentley and MechanicalSpace Joint Developers deliver productivity-enhancing and quality-improving desktop solutions for mechanical designers, drafters, engineers, and manufacturing professionals.**

MechanicalSpace Integration Technology

- MicroStation BASIC, Visual Basic, C, C++, MDL
- Over 2,000 functions through API's
- Integrated assemblies, solids, surfaces and wireframes
- Support for standards included (e.g. STEP, IGES, ACIS, OLE)
- Multiple platforms: DOS, Windows, UNIX, MAC
- Single user interface
- Single engineering model

MDL Basics

- **Introduction**
  - MDL Fundamentals
  - MDL Applications
  - Performance considerations
  - The MDL Runtime Environment
  - MDL Development Utilities
  - Files Types
  - Resource source files
  - Dialog Box Manager
  - MDL Application Organization

MDL Basics

- MDE Workspace
  - Tools Menu
  - MDE On-line Help
- Design Methodology
  - Functional specification
  - High-level MDL application design
  - Project task list
  - Designing a Dialog Box
  - Implementing Command Processing
  - Basic Application Architecture

MDL Basics

- MicroStation Resources
  - An Overview of Resources
  - Benefits from using resources
- Language Concepts
  - Element Descriptors
  - Standard C Functions
  - Dynamic Link Modules
  - Database Manipulation

MDL & MechanicalSpace

- Feature Engine
  - Asynchronous Feature Functions
  - Feature Linkage Functions
  - Miscellaneous
- Solid Modeling Engine Functions
  - Entity List Functions
  - Solids Creation Functions
  - Solid Boolean Operation Functions
  - Edge Blending Functions
  - Inquiry Functions

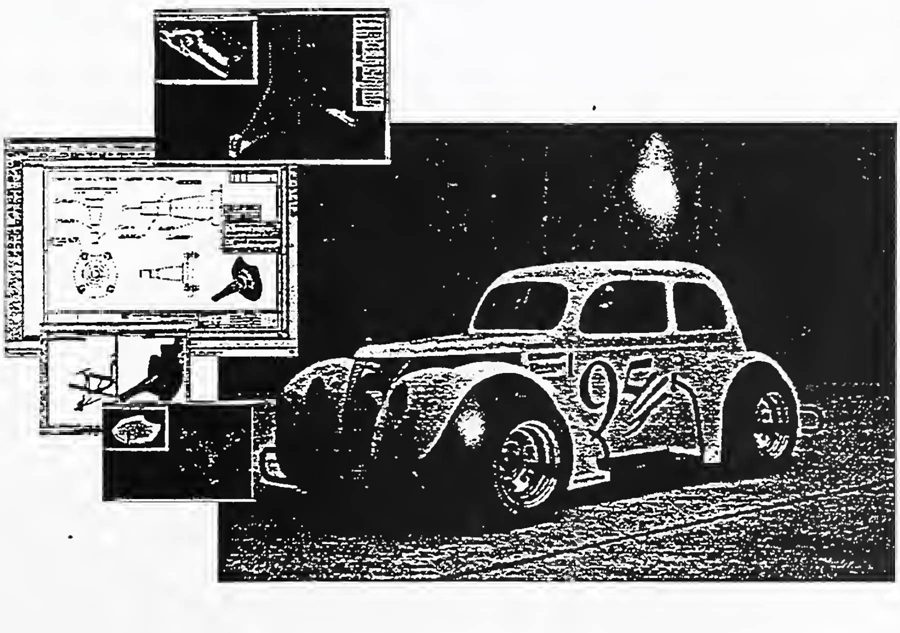
MDL & MechanicalSpace

- Solid Modeling Engine Functions (continued)
  - Entity Type Functions
  - Intersection Functions
  - Sweeping Functions
  - Measurement Functions
  - Save and Restore From Disk Files
  - Node Id Attachment and Extraction Functions
  - Miscellaneous Solid Modeling Functions
- Modeler Engine and Miscellaneous Functions

Summary

- MDL vs. other 3rd party MCAD development environments
  - More extensive set of development tools
  - Complete access to MicroStation Modeler (and ACIS) core
  - COSMOS/M DESIGNER II analysis and ESPRIT/MS manufacturing solutions developed in MDL

Single Engineering Model



Appendix C5

Business and Operations Requirements

Visions of CAD Compatibility

Peter V. Buca
Future Products Manager
Parker Hannifin Corporation GTFSD

Clarifications

- Perceptions of one Aerospace Supplier
- High-Level Overview
  - Occasional Dives below 30,000 feet
- Ask **when** you want to know
- Contacts Afterwards
  - PeterVB@gnn.com
  - (216) 531-3000

Overview

- Gas Turbine Supply Chain
  - Historical CAD Usage
  - Parker's Position
- The Vision
- The Reality
- Gap Analysis

Gas Turbine Supply Chain

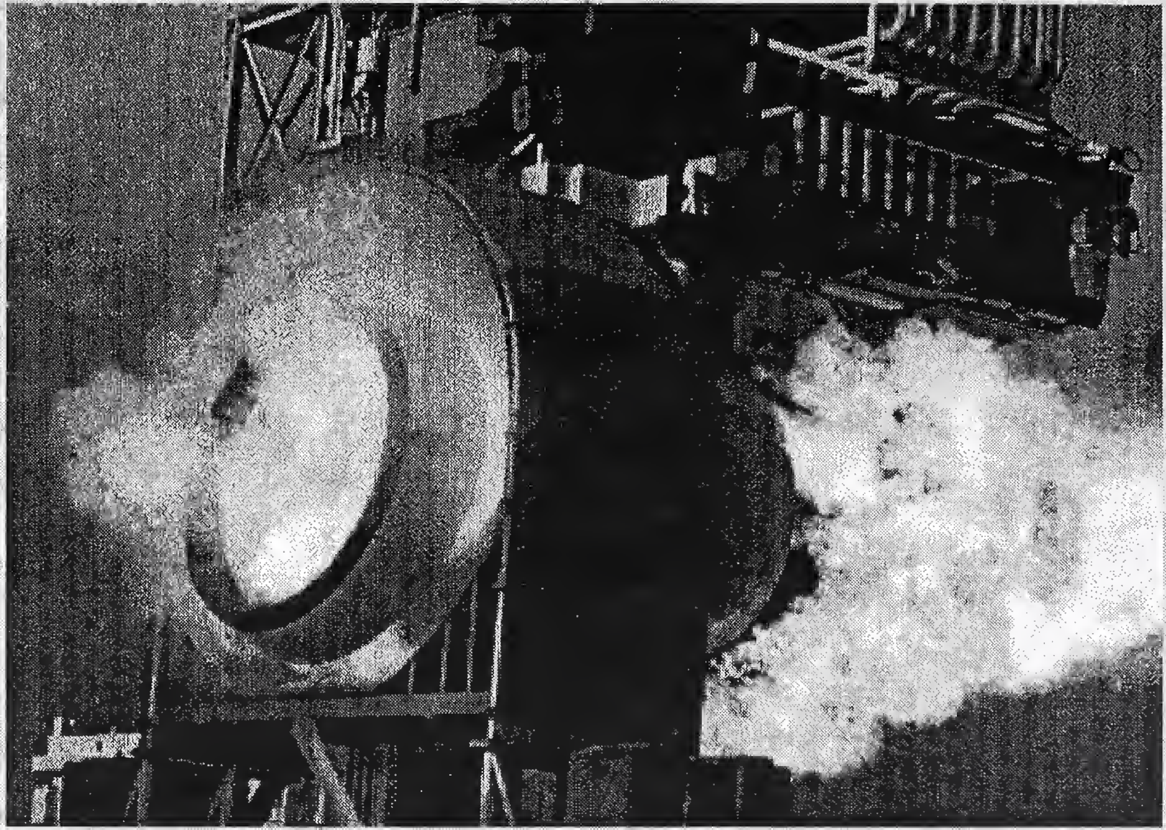
Engine Buyers
Aerospace - Boeing, Airbus, MacDonnell
Industrial - S&S, ABB, Westinghouse

Engine Suppliers
General Electjric, P&W, RR,
ABB, Siemans, Westinghouse
EGT, Ulstein, Allison, AlliedSignal

Accessory Suppliers
Parker Hannifin, Hamilton Standard, Abex JWL,
Woodward Governor, AlliedSignal,
Elano, Colt Industries, etc.

Operation Suppliers
Special Processes, Components,
Testing Services, Chip Cutters,
Prototype Mfg.'s, Materials, Forging, Casting,

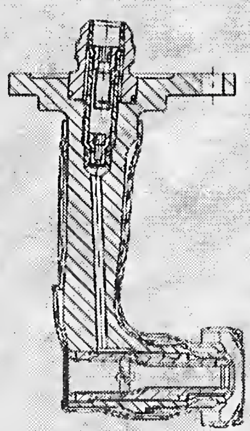
Complex Requirements



CAD History

- Alignment with Aircraft Suppliers
  - Boeing: IBM/Dassault - CATIA/CADAM
  - McDonnell Douglas: Unigraphics
- Evolving Expectations
  - Electronic Drafting Board
  - 2D Electronic Model
  - 3D Electronic Model
  - Prototyping, Speed

Parker Product Evolution



Parker CAD System

- 1978-1993
  - One CAD System
  - CADAM on Mainframes
- 1994-1998
  - Two CAD Strategy
  - ProEngineer/ProCADAM on Workstations
- 1998 and Beyond
  - Windows NT and Multi-CAD Strategy?

The Vision

- Concepts brought to market with utmost speed enabled by concurrent supplier/ customer teams employing shared 3D models for design, analysis, prediction, assembly proofing, manufacturing, configuration and quality control.
- The “Pitch”: Purchase the Vision

The Reality

- No One System Best at Everything
  - Analysis, Assembly, Component Design
  - Multiple Models necessary
- Imposed Standards Waste Resources
  - Training and Support
  - Software and Hardware Costs
  - Configuration Management
- Complete Absence of Reliable Transfers
  - Compatible Software Systems

Gap Analysis

- User Community speaks CAD Products not Standards Language
  - PTC Camp vs. EDS Camp vs. Dassault Camp
- CAD Suppliers Differentiate on Features not Effectiveness of Support or Adherence to Standards
- Usage Models
  - Complex/Simple, System/Component, etc..
  - Drive Acquisition/Consolidation