NIST Manufacturing Process Planning and CAME Forum Workshop

Joint Technical Meeting
Gaithersburg Marriott Washington Center
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Draft Workshop Proceedings

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ACRONYMS

AI	Artificial Intelligence
CAME	Computer-Aided Manufacturing Engineering
CAD	Computer-Aided Design
API	Application Program Interfaces
R&D	Research & Development
NIST	National Institute of Standard and Technology
IT	Information Technology
ISO	International Standards Organization
CAM	Computer-Aided Manufacturing
WWW	World Wide Web
CAPP	Computer-Aided Process Planning
VRML	Virtual Reality Modeling Language
OLE	Object Linking and Embedding
CORBA	Common Object Request Broker Architecture
STEP	Standard for the Exchange of Product Model Data
DFx	Design for Manufacturing, Design for Assembly, Design for Costs, etc.
PDM	Product Data Management
ECO	Engineering Changer Order
VLSI	Very Large Scale Integrated Circuit
SQL3	Structured Query Language 3
DCE	Distributed Computing Environment
Cyc	CyCorp’s Product Cyc
KA	Knowledge-based Agent
OO	Object-Oriented
OMG	Object Management Group
PC	Personal Computer
IDL	Interface Definition Language
BPR	Business Process Re-engineering
ROI	Return of Investment
PP	Process Planning
IGES	Initial Graphics Exchange Specification

MRP	Material Requirement Planning
ERP	Enterprise Resource Planning
EDM	Engineering Data Management
MES	Manufacturing Execution Systems
NC	Numerical Control
AP	Application Protocol
CMM	Coordinate Measurement Machine
NSF	National Science Foundation

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, 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 was 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 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 design 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.

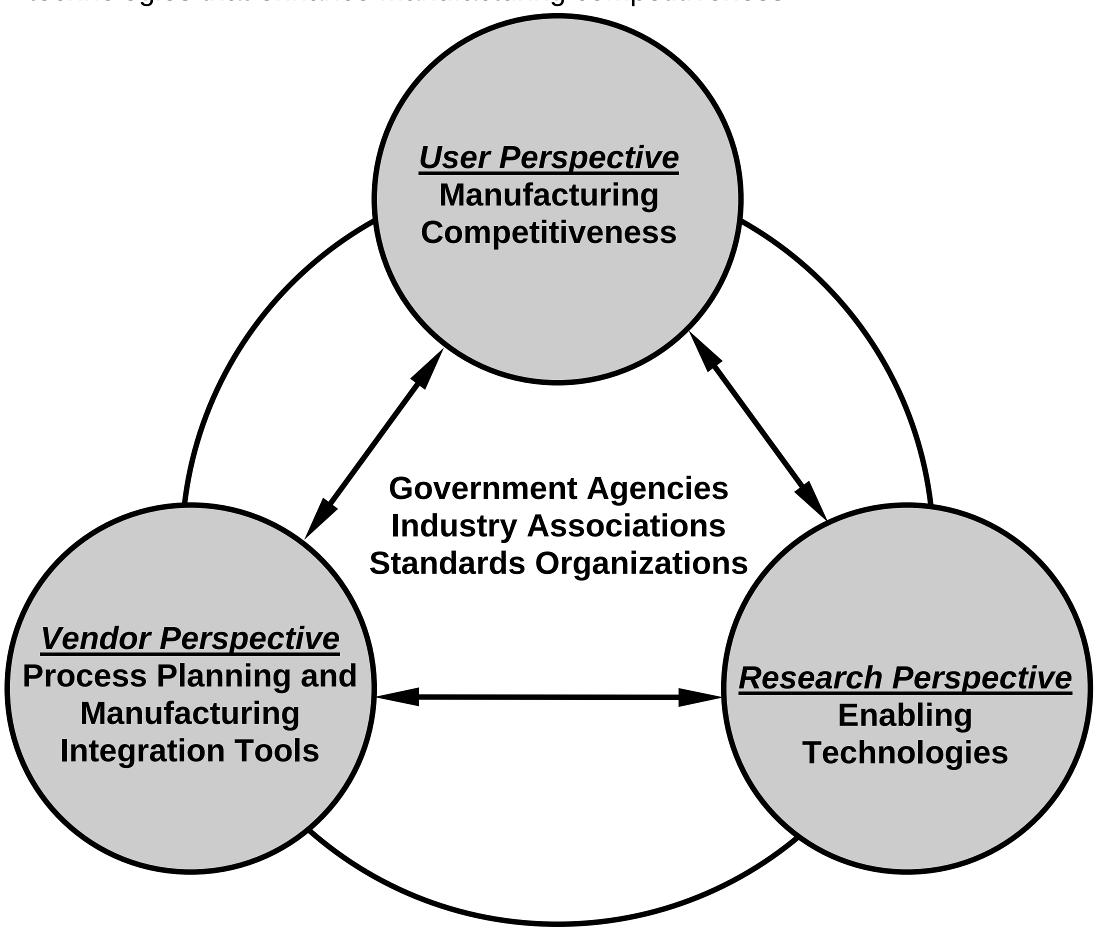


Figure 1. Relationships Among Manufacturing Stakeholders

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 and 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

[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.

staff, visiting researchers, and collaborators. Specific NIST activities include the 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, and 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
<u>Near</u> 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

* 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*
Agents	Dynamic planning	Human-computer interface	Basic research
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.

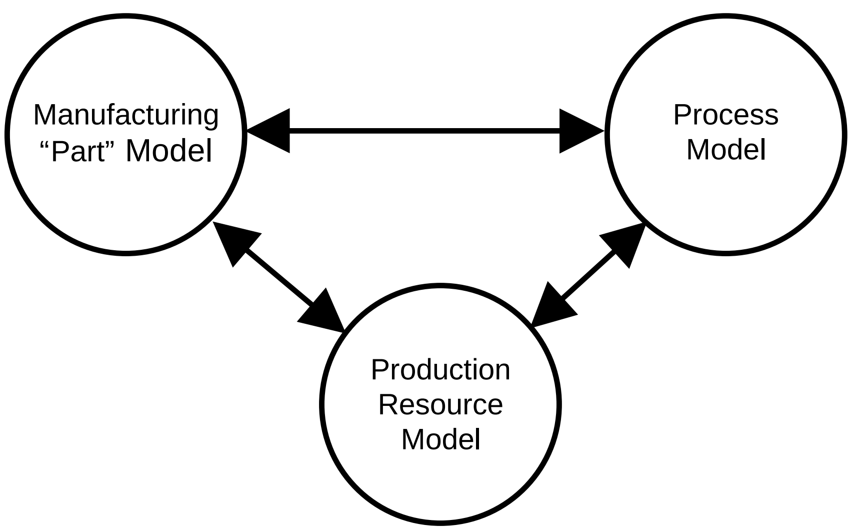


Figure 2. Process Planning and Product Data Modeling Relationships

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 SQL	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
SQL3, 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.

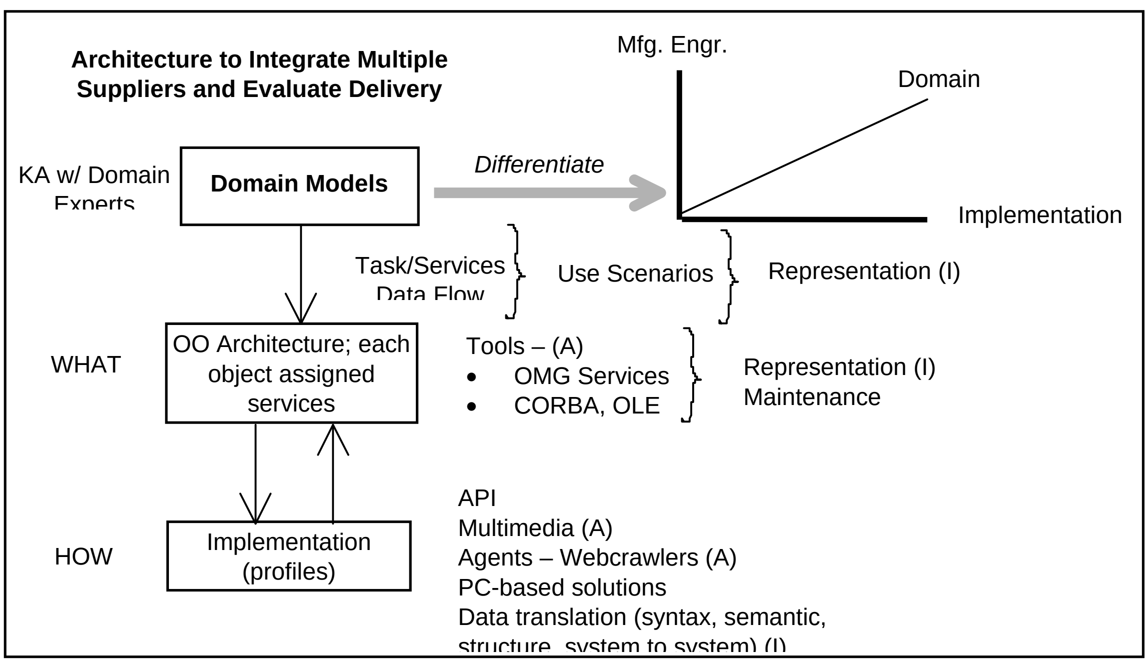


Figure 3. Approaches (A) and Issues (I) in developing the IT Paradigm

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.

Category	Technology Topic
Integrated planning	Integration of technologies to develop producibility and cost predictors for design systems that also suggest appropriate 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 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

Category	Technology Topic
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):

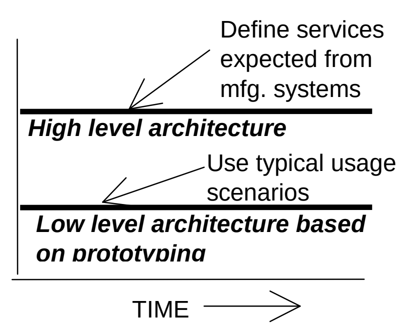
1. Architecture and tool integration (Suzanne Barber)
2. Business needs/experience/research exchange (Bill Hlavacek/Steve Haberman)
3. Dynamic process planning (Ezat Sanii)
4. Feature recognition and representation (Yong Se Kim)
5. Integrated planning (Caroline Hayes)
6. Multi-domain process planning (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 significantly 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, GPP, Gov. Reqd. 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 mfg 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 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 mfg 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.
    - ∗ Then what are the assembly features?
    - ∗ How much of assembly information is “procided” (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 on 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

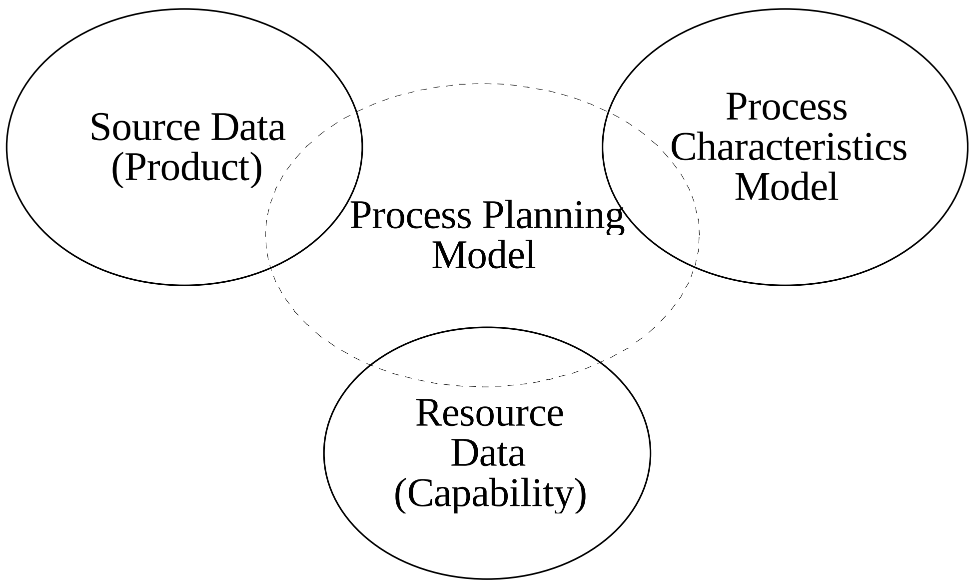


Figure 4. Process Planning Model Relationships

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.

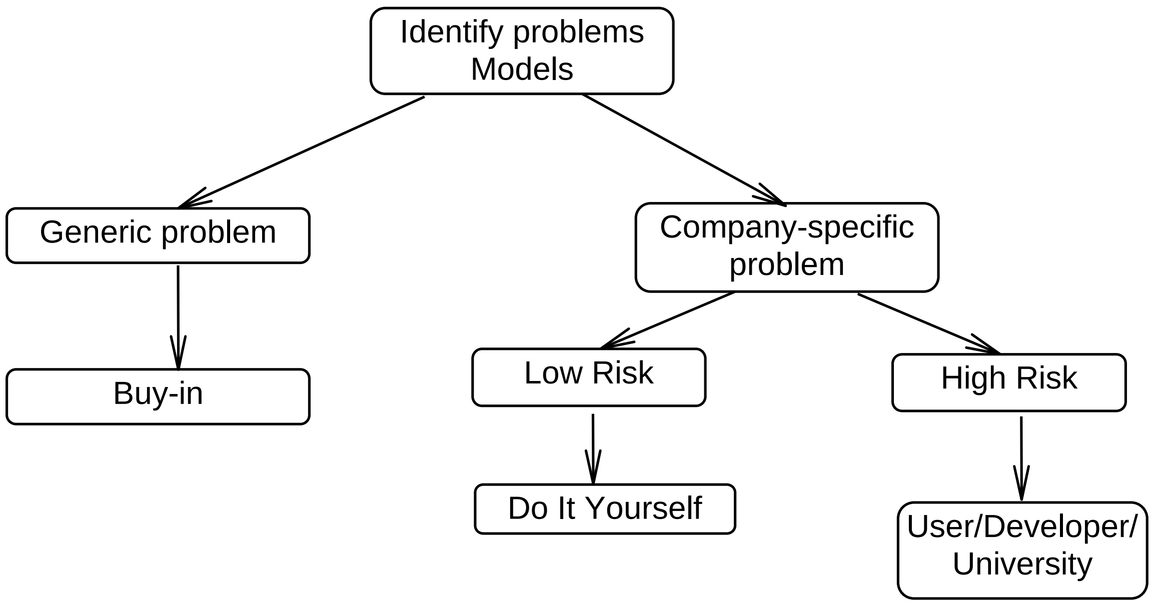


Figure 5. Decision Tree for User/Manufacturer Role in Process Planning Development Activities

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	• Be clear on 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 organization sees 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

Appendix A. Workshop Participants

NIST MANUFACTURING PROCESS PLANNING WORKSHOP

AND

CAME FORUM WORKSHOP

--List of Participants--

June 10-11, 1996
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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
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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)	Facilitator	1:00-2:30 PM
• 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?		
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