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Computer-Aided Process Planning Revolutionize Manufacturing

Puneet Bhatia

Mechanical Engineering Department,
University of Louisiana at Lafayette

Dr. Terrence. L Chambers

Mechanical Engineering Department,
University of Louisiana at Lafayette

Abstract

Process planning translates design information into process steps and instructions to efficiently and effectively manufacture products. It is a task that requires a significant amount of time and experience. Manufacturers have been pursuing an evolutionary path to improve and computerize process planning in the various stages. Computer-Aided Process Planning (CAPP) has evolved to simplify and improve process planning and achieve more effective use of manufacturing recourses. This paper discusses the benefits of CAPP and how it has revolutionized manufacturing.

Introduction Survey

In early 1950's Numerical Control (NC) machines were first introduced, which sparked the research and development of Computer-Aided Manufacturing (CAM). Later, a sketchpad system developed by Ivan Sutherland in early 1960's resulted in a milestone achievement in computer graphics and marked the beginning of Computer-Aided Design (CAD). In industry, engineers extensively use both CAD and CAM but there is very little communication between the two. Computer-Aided Process Planning emerged as the communication agent between CAD and CAM. The CAPP system solves planning activities, such as selection of cutting tools, determining calculations of cutting parameters, tool path planning, generation of NC part programs, etc.

Process Planning

Requicha and Vandenbrande [1988] describe process planning in the following way, "A process planner and a set-up planner (often the same person) examine a part's blueprint and consult various files and handbooks to produce specifications and information on fixtures and clamping devices to be used, and on set-up of the work piece on a machine tool.

Set-up specifications are typically conveyed through annotated sketches or engineering drawings."

A process plan will vary from factory to factory, but there are some basic elements to be found in all. Process planning encompasses the activities and functions to prepare a detailed set of plans and instructions to produce a part. Process plans typically provide more detailed, step-by-step work instructions including dimensions related to individual operations, machining parameters, set-up instructions, and quality assurance checkpoints. Manual process planning is usually based on the manufacturing engineer's experience and knowledge of production facilities equipment, their capabilities, processes and tooling.

The automation of process planning is described through five stages, which were developed over the years as an evolutionary path to improve and computerize process planning. The five stages of process planning are described in Fig. 1. Different Companies may have implemented CAPP at different levels.

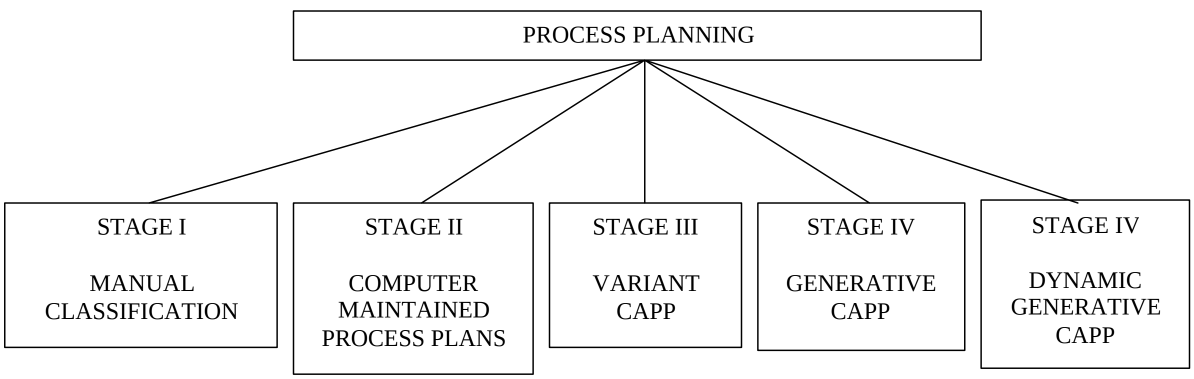


Fig. 1: Different Stages of Process Planning

Evolution of Computer-Aided Process Planning

In Stage I, the manufacturer divides the parts of a product into families and develops standard process plans for parts families. When a new part is introduced, the process plan is manually retrieved, marked-up and retyped. Standardizing process plans has improved quality but has not improved the quality of the planning of the processes. It neither easily takes into account the differences between parts in a family, nor improvements in production processes.

In Stage II, process plans can be stored electronically once it was created in Stage I. Manufacturers can retrieve it, modify it for a new plan and print the plan. Table driven cost and standard estimating systems were other capabilities of this stage. Typical process plan is a single common process for the part family, substituting planning of individual processes for every part separately. Part family, for which the typical plan is established, belongs to the parts technological type. Fig. 2 shows the process, flowchart for process plan selection [3]. Here, it is assumed that typical process plan database exists. One should give attention to correct understanding of typical process plan and its realization in production process. Although, the process plan is typical, practical realization can be different.

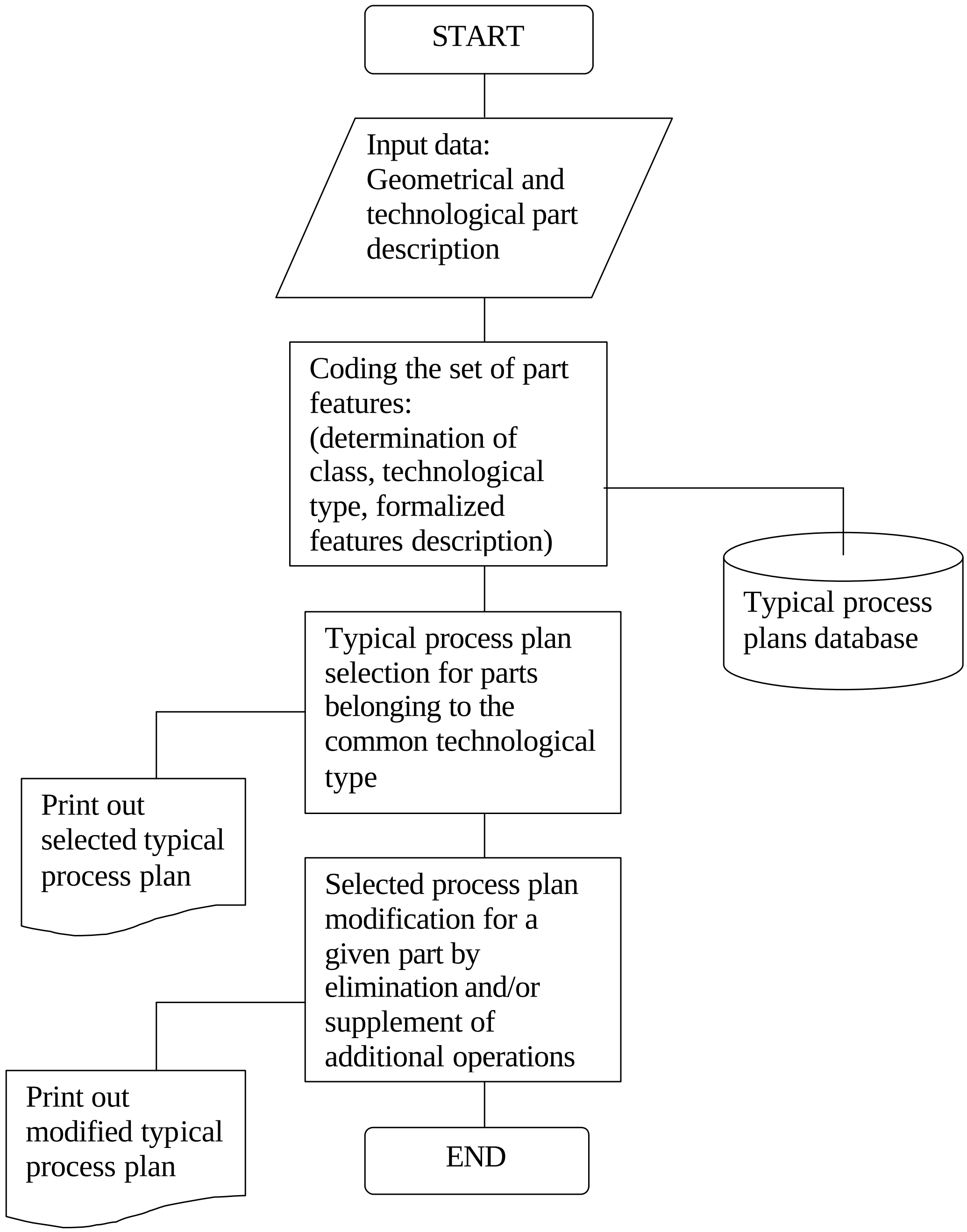


Fig. 2 The flowchart for a typical process plan selection

In 1958, Mitrofanov (Russian engineer) formalized the concept of Group Technology (GT). Group Technology is the "realization that many problems are similar, and that by grouping similar problems, a single solution can be found to a set of problems thus saving time and effort" Solaga [4]. GT examines products, parts and assemblies. It then groups similar items to simplify design, manufacturing, purchasing and other business processes. Fig. 3 shows the flowchart of group technology for design application.

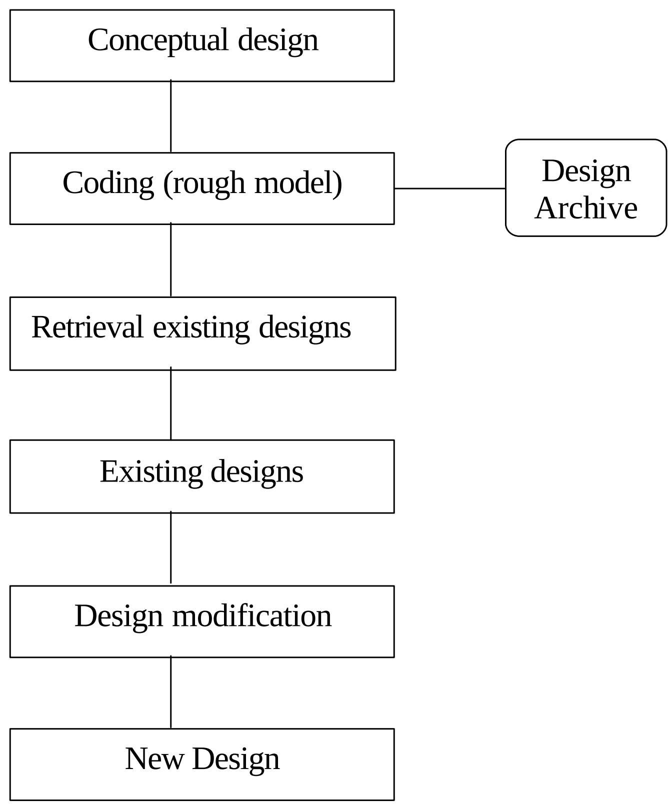


Fig. 3 Group Technology for Design Application

Variant CAPP was the initial stage of the Computer-Aided Approach (Stage III). This stage is based on Group Technology (GT) coding and classification approach to identify a large number of part attributes or parameters. These attributes allow the system to select a baseline process plan for the part family and accomplish ninety percent of the planning work. The planner will add the remaining ten percent of the effort by modifying or fine-tuning the process plan. The base-line process plans are manually entered using a super planner concept, which is developing standardized plans based on the accumulated experience and knowledge of multiple planners and manufacturing engineers. There are three types of coding, hierarchical, chain and hybrid codes. Hybrid code is the one that is most widely used. Group technology benefits manufacturing in many ways. It reduces the number and variety of parts. It reduced cost and accelerates product development. It has also simplified process planning and improved costing accuracy. In a variant CAPP system, the process plan is assigned for the whole part according to global part information. Parametric information between the technological operations and the part feature does not exist. Fig. 4 shows the details of variant process planning.

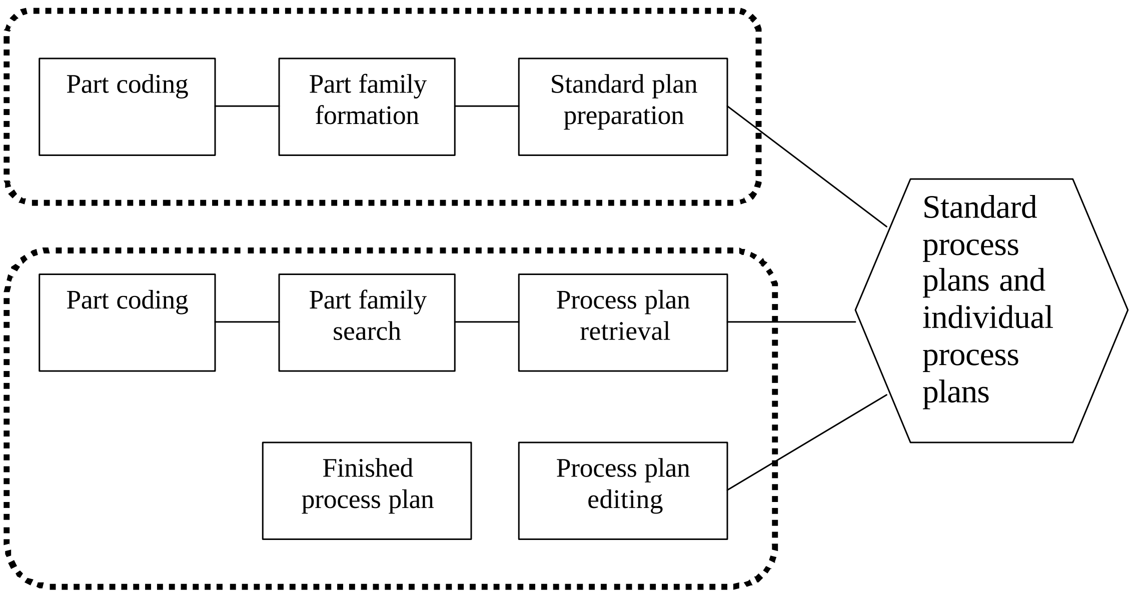
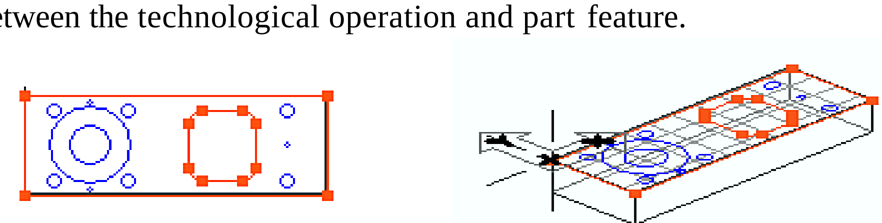


Fig. 4 Variant Process planning

In Stage 1V, generative CAPP, the process plan for a new part is automatically synthesized. The generative CAPP system, also called as an exact system, creates the process plan from the information available in manufacturing databases according to a CAPP methodology. This system operates with very little human intervention. The creation of the process plan depends upon the part features. Each of the part features can be manufacturable by several technological operations. For individual features from the manufacturing knowledge base, the process operations are generated. From a set of process operations, an optimal aggregate of technological transformers is extracted. There is parametric information between the technological operation and part feature.



(a) (b)

Fig. 5 Drawing of JackTop Pocket Side (a) Top View (b) Isometric view

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An example of generative CAPP is shown as follows. To manufacture the part (JackTop Pocket Body) shown in Fig. 5 (b), the part is first drawn in a Computer-Aided Manufacturing tool called Virtual GIBBS CAM. The tools' dimensions and information were identified in each process in GIBBS. One can see each process being done. This way, any mistakes done can be corrected before the part is manufactured. The part is 5.75"x2"x0.98" and made out of aluminum bar block. The processes required for making the JackTop Pocket Body are shown in Table 1 and Fig 6. The part is finally manufactured as shown in Fig. 7.

PROCESS #	TOOL TYPE	PROCESS
(i)	3" Face Mill	Face Mill surfaces from right to left with no offset
(ii)	1/2" End Mill	Used to produce the rectangular pocket.
(iii)	1/2" Spot drill and later 47/64" Twist -Drill	Center-drill 10places, @ 0.03" tip depth for dowel pin holes, @ 0.150" tip depth for 6 bolt holes andcenter of risen hole. Drill through 1" full depth.
(iv)	1-1/2" Insert Drill	For roughing round pocket, 1/2" deep.
(v)	3/4" Reamer	Ream through 1.1" deep.
(vi)	1.505" Boring Bar	Finish bore 1/2" deep.
(vii)	0.116" Twist-Drill	Peck-drill 0.6" tip depth (3) places for dowel pins
(viii)	1/8" Reamer	0.500 deep (3) places for dowel pins
(ix)	17/64" Twist-Drill	Peck-drill through Full depth, 6places

Table 1 Process plans for JackTop Pocket Body

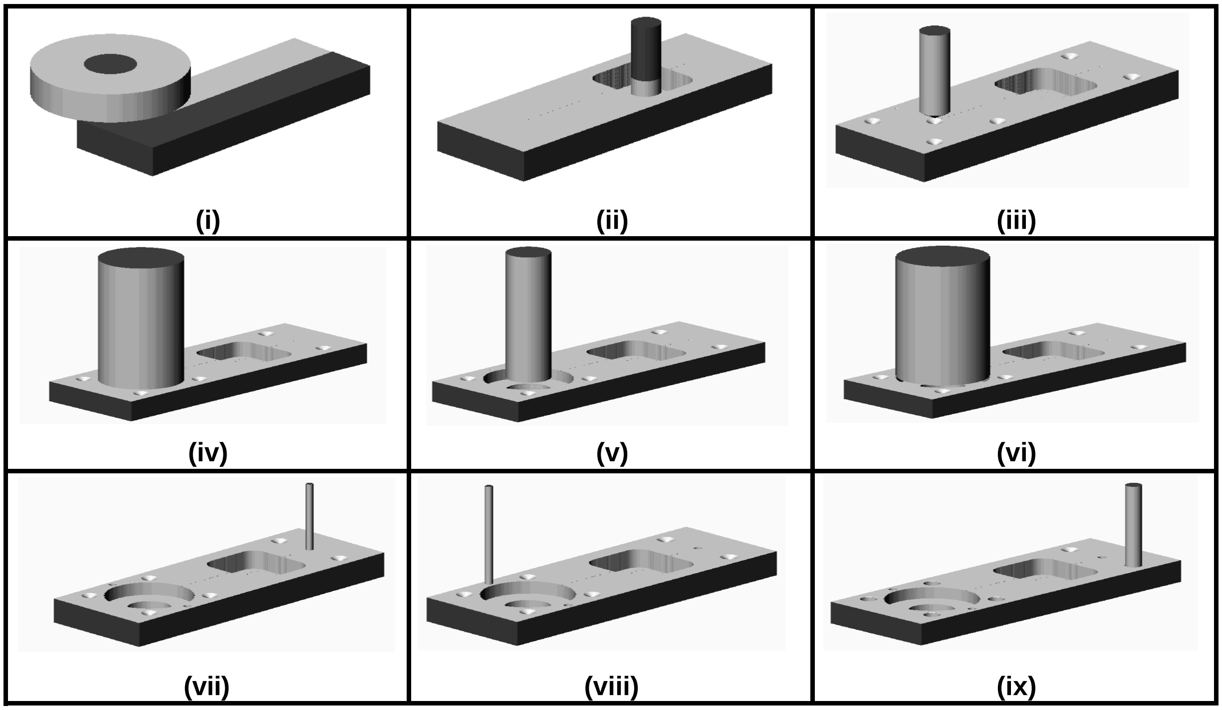

Fig. 6 Processes Used To Make Jacktop Pocket Body

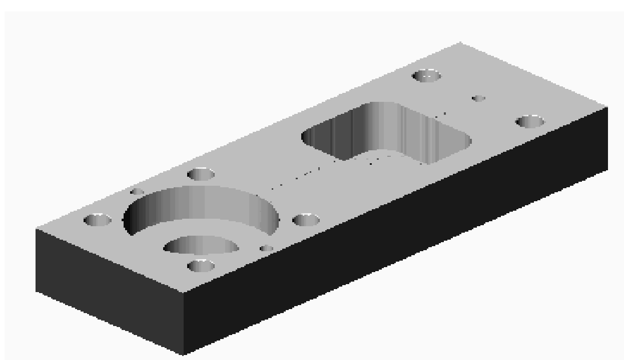

Fig. 7 Completed Part Of Jacktop Pocket Body

The manufacturing knowledge is one of the basic information bases for automated process planning. The manufacturing knowledge in the variant CAPP is placed in standard plans for each family group. Knowledge is expressed in complex manufacturing, fixturing, and heat treatment instructions. The knowledge in Generative CAPP Systems is placed in the individual bases. They should consist of information on manufacturing methods, manufacturing equipment, fixturing, heat treatment, product feature structure, etc. The knowledge is directly expressed and is represented in various representation schemes (production rules, frames, decision trees, decision tables, semantic nets). Both approaches require different way of describing the part properties. The Generative CAPP system needs the unambiguous description for the geometrical, topological and technological part properties. In the Variant CAPP approach, it is convenient to have ambiguous part information (e.g. GT codes: Opitz, CODE, Miclass, Dclass code). The differences between variant CAPP and generative CAPP are shown in Table 2.

Activity-task-parameter	**Variant CAPP**	**Generative CAPP**
Description of part	Unambigious	Ambiguous
Integration with CAD	Partial	Complete
Elaboration of CAD data	Partial	Complete
Simulation	No	Yes
Optimization of sequencing of process operations	No	Yes
Optimization of cutting conditions	Yes	Yes
Used programming	Foxbase.	Delphi,
Languages	Visual Fox	VB, C++
Location of manufacturing knowledge	Process plans	Individual databases
Expression of manufacturing knowledge	Implicit	Explicit

Table 2 Differences between Variant CAPP and Generative CAPP

At Stage V, process plans are developed using Dynamic Generative CAPP. Dynamic Generative CAPP varies over time depending on the resources and workload in the factory. For example, if a primary work center for an operation(s) was overloaded, the generative planning process would evaluate work to be released involving that work center and, alternate processes and related routings. The decision rules would result in process plans that would reduce the overloading on the primary work center by using an alternate routing that would have the least cost impact [2].

Dynamic generative CAPP also implies the need for online display of the process plan on a work order oriented basis to insure that the appropriate process plan was provided to the floor. Tight integration with a manufacturing resource planning system is needed to track shop floor status and load data. Finally, this stage of CAPP would directly feed shop floor equipment controllers or, in a less automated environment, display assembly drawings online in conjunction with process plans. Due to the dynamic aspects of process planning, each process plan should contain alternatives for each operation. Use of alternative methods to produce a part may be required for some of the following reasons:

1. A certain machine may be undergoing repair or may be busy manufacturing another part or batch. An alternative machine could be used, reducing the throughput time of that part, and also the work in process (WIP). With the presence of alternatives, in the case of a disruption in the shop floor (for example a machine tool failure), it will not be necessary to re-plan the manufacture of the part, since an alternative may be available.

2. At the equipment level, if a certain cutting tool is unavailable, an alternative tool could be used to machine a specific feature.

3. The batch quantity may influence the choice of an operation. For example, for a small batch quantity, a certain operation may result in a shorter manufacturing time, whereas for greater quantities another operation may be appropriate for shortening the manufacturing time, even if the latter operation requires the setup of a new tool. For instance, if only one part is being produced the most effective strategy to produce it is to use tooling already mounted and qualified on the machine if possible. Setting up new tooling on the machine almost always takes far longer than using existing tooling, even if the latter is less efficient from a machining time standpoint. This can also be extended to the case of various machines available to perform the same job.

CAPP Benefits

Significant benefits can result from the implementation of CAPP. Based on past research and detailed surveys using generative-type CAPP systems, the following estimated cost savings were achieved:

- 58% reduction in process planning effort
- 10% saving in direct labor
- 4% saving in material
- 0% saving in scrap
- 12% saving in tooling
- 6% reduction in work- in-process

In addition to above benefits, there are intangible benefits as follows:

- Reduced process planning and production lead-time; faster response to engineering change
- Greater process plans consistency; access to up-to-date information in a central database
- Improved cost estimating procedures and fewer calculation errors
- More complete and detailed process plans
- Improved production scheduling and capacity utilization
- Improved ability to introduce new manufacturing technology and rapidly update process plans to utilize the improved technology

Conclusions

CAPP contains generic process plans and the provision for process planner to add data into the database. Alternate process plans are considered and the optimum one is displayed. There are significant advantages to implementing CAPP, consisting mainly of a reduction in process planning effort, and in direct labor savings.

Future Directions

A direct link with the CAD database and the use of an expert system to facilitate data input would ease the burden of inputting data. Fuzzy neural networks could help in synthesizing the knowledge that is needed for process planning. Feature-based design and concurrent engineering address the integration of CAPP and design functions. Also, object-oriented programming could be used. The object-oriented programming paradigm meshes with the way people naturally interpret the world. With object-oriented programming, well-structured complex systems with high efficiency and convenience can more easily be constructed. To increase flexibility on the shop floor, alternative process plans ought to be given rather than selecting one too early to give only one optimum plan. It is noted that the systems which have been used in industry allow participation of the user in the decision making process. This perhaps is one of the reasons for the popularity of variant systems. Some systems support both variant and generative capabilities, which could be a new trend for CAPP systems.

A system using fuzzy neural networks in the individual modules of CAPP would lead to more understanding of the structure, behavior and outcome by the users. An object-oriented programming structure would give modularity, which facilitates customization and expansion of the system. CAPP systems should include human input in the process. Artificial intelligence techniques like formal logic, describing components, and expert systems for codifying human processing knowledge are also applicable to process planning problems. The CAPP system could be used to give feedback to the designer to evaluate the manufacturability of the design so that some potential manufacturing problems could be exposed and eliminated at the early design stages. It can offer a framework and open architecture in which all kinds of advanced artificial intelligent techniques (e.g. multi-agent) can be effectively applied and all kinds of optimization algorithms and development tools can be integrated easily to build a sophisticated and practical CAPP system.

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PUNEET K. BHATIA
Puneet Bhatia is scheduled to receive his Master of Science in Mechanical Engineering in the Summer 2004 from the University of Louisiana at Lafayette. Her research interests include Artificial Intelligence, Programming, and Engineering Optimization. She received his Bachelor of Science in Electrical Engineering from University of Oklahoma, Norman in December 2001. She is a student member of the ASME and SWE.

TERRENCE CHAMBERS
Dr. Terrence Chambers currently serves as an Assistant Professor of Mechanical Engineering at the University of Louisiana at Lafayette. His research interests include engineering design and optimization, artificial intelligence, genetic algorithms and genetic programming, engineering software development, and numeric and symbolic solutions to engineering problems. Dr. Chambers is a registered Professional Engineer in Texas and Louisiana.