SRC TR 88-12

Automatic Generation of NC Part Programs

by

M.E. Ssemakula and P.O. Sivac

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Mukasa E. Ssemakula and Philippe O. Sivac
Department of Mechanical Engineering & Systems Research Center
University of Maryland,
College Park, MD 20742, USA

ABSTRACT

Most CAD/CAM systems available today are capable of generating NC part programs to machine a component designed on the system. This achieves apparent integration between CAD and CAM. However, the user must still manually enter crucial manufacturing data such as cutting conditions, tooling and machine information. An automated process planning system would have the capacity to provide this information directly. This paper describes one such system which generates a process plan and, automatically, the NC part program and can therefore be used as the basis of true integration between CAD and CAM.

INTRODUCTION

With the increased factory automation and usage of numerically controlled (NC) machines, the generation of NC part programs has come to be of prime importance in manufacturing and significant productivity improvements can be achieved through automation of this function. One of the first steps in helping develop part programs has been to create higher level numerical control languages such as APT, COMPACT II and GNC. Instructions, written in that language are then converted by the computer system to a set of commands which the NC machine recognizes. The next step was to provide an interface to computer graphics to help enter geometric information. These elements form the basis of Computer Aided Manufacturing (CAM), and when the geometry is generated on a Computer Aided Design system, CAD/CAM. Nevertheless these systems remain only tools to aid the manufacturing engineer,who is still required to provide crucial manufacturing data to the system in order to generate working NC part programs. He must determine the sequence of operations to machine the part, provide the optimal cutting conditions for each operation (speed, feed, depth of cut), and select the proper cutting tool, as well as machine tool. All this data originates from the process planning function, which has not been included in CAD/CAM systems. The goal of this paper is to describe how the development of computer-aided process planning (CAPP) systems can lead to the automatic generation of NC part programs, and play a major role in the development of Computer Integrated Manufacturing. This concept has been successfully implemented in a CAPP system for prismatic parts. The NC part program generation modules will be described and a fully processed example will be presented.

COMPUTER-AIDED PROCESS PLANNING

DEFINITION

Process Planning is defined as the task of translating part design specifications into manufacturing instructions required to convert a part from a rough state to a finish state. This function takes up approximately 40% of the preparation time for a new part. Traditionally, it is performed manually by highly skilled workers who possess in-depth knowledge of the manufacturing processes involved and the capabilities of the machine tools. On the basis of their experience, they are expected to develop a detailed process plan to be used in manufacturing the part. This involves selecting the appropriate machine tools, jigs and fixtures, determining the appropriate machining operations and associated cutting conditions, as well as calculating the cutting times and the non-cutting times. A detailed knowledge of the particular manufacturing environment is necessary because it imposes constraints on available alternatives. The result is a detailed process plan which includes machine tools to be used, sequence of operations, tool and fixture selection, and cutting conditions. This activity is very labor intensive and becomes often tedious when dealing with a large number of process plans and revisions to those plans. Rather than carry out an exhaustive analysis and arrive at optimal values, which would be too time consuming, process planners all too often tend to play safe by using conservative values. What is considered to be conservative varies with the particular manufacturing environment. This has the unfortunate side effect that if several process planners with different backgrounds are given the same part to plan, they will likely come up with different plans. Even more significantly, the same planner, if required to generate a plan for the same part on different occasions will probably come up with inconsistent results. Consequently, the speed and consistency brought about by the computer was sought in process planning. Another factor is the lack of qualified and experienced process planners. Typically, process planners have a significant experience in a machine shop and are over 40 years of age. It is estimated that the U.S. industry requires about 200,000 to 300,000 process planners, and only 150,000 to 200,000 are currently available [1]. Thus, another advantage of the use of computers in the process planning function is that it can reduce the required skill of a planner. CAPP can be implemented at two levels:

- Stand-alone systems

  As a stand-alone system, CAPP can generate process plans faster and with better consistency than human process planners. CAPP systems, for example, can calculate optimum cutting conditions based on varying criterias such as minimizing costs, minimum tool wear, or shortest cutting time. With the use of artificial intelligence (AI) techniques, they can incorporate manufacturing rules to select and sequence the appropriate processes to complete the process plan. Computers can thus free expert process planners to work on cases which fall outside the scope of the CAPP system.

- Within the Computer Integrated Manufacturing (CIM) architecture

  CAPP's function is to transform the part design into manufacturing instructions. This requires the use of the part geometry as well as design information. Based on this the system calculates the detailed data required for manufacturing as outlined above. CAPP appears thus as the ideal candidate to fully integrate CAD and CAM (Figure 1). Use of CAD/CAM systems as they are known today, shows that generation of a 3-D model provides only geometrical support for machining yet will not yield NC part programs without extensive interaction with the user. Also, CAD/CAM systems are not sufficient to integrate with the other building blocks of CIM. The CAPP link will provide the time information necessary for planning and scheduling by calculating machining times. Thus, in addition to the automatic generation of the relevant technical data such as cutting conditions and manufacturing sequence, CAPP could also provide timing information to the MRP II system as suggested in a proposed CIM architecture [2].

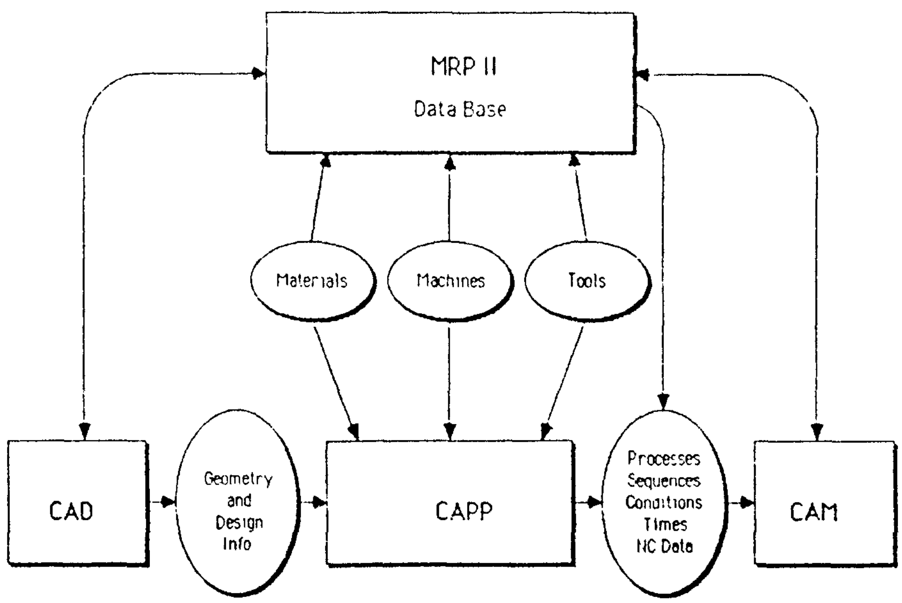


Figure 1: CAPP's role in a proposed CIM model.

IMPLEMENTING CAPP

There are two major approaches to CAPP currently found in the literature.

The first approach is based on coding schemes for retrieval of prior process plans. This is called a variant approach and is based on the concept of Group Technology (GT). For a given family of parts, the detailed process plan for a representative member of the family is developed with the help of an experienced process planner. Plans for several part families are similarly developed and stored on the systems database. The major characteristics of the new part are used to retrieve a previous process plan for a part in the same family which has similar features. The retrieved process plan can be modified easily to match the new part. Designing a new process plan thus consists of retrieving the standard process plan for a family of parts and tailoring it to the characteristics of the part. Examples of such a system are MIPLAN [3], DCLASS [5] which have been implemented in the industry.

The second approach is generative and creates a new process plan for each part. Generative CAPP systems use their own internal logic to derive a new process plan based on the charateristics of the part and the machine it is to be manufactured on. AUTAP [4], APPAS [6] are examples of these systems. The development of Artificial Intelligence (AI) based expert systems has had a significant impact in CAPP research (Gari [7], SIPP and SIPS [8]) . These systems offer the advantage of being modular and keeping track of the rules to justify a conclusion. Manufacturing processes, their sequencing, and required cutting tools can all be determined on the basis of these rules.

The advantage of variant systems is that they can be implemented in the industry fairly easily, however they do not truly solve the problem of automating the process planning function since they still rely on human process planners to develop representative process plans and review them for possible new applications. The generative approach can create new process plans for parts which fall into its scope. Therefore a new, complete and up to date process plan is created for every new part with little human intervention. It is estimated that generative process planning systems have the potential to reduce the planning labor costs by 60% [9]. Also, because it requires detailed part characteristics as input, it can serve as the basis for generating NC part programs.

Most of the CAPP systems available today are of the stand-alone type. There are few systems described in the literature which generate NC part programs from CAPP. Eversheim describes one such system, AUTAP-NC [10] , for rotational parts and sheet metal stamped parts. The National Bureau of Standards' Automated Manufacturing Research Facility (AMRF) used this approach to generate the part programs for a particular milling machine from a process planning system integrated with a design and NC code generation package [11]. The system described here is based on a generative CAPP program for prismatic parts. Using information stored in the process planning function, as well as extra geometric information, it is possible to generate complete NC part programs automatically.

ICAPP

OVERVIEW

ICAPP is a computer aided process planning system developed for prismatic parts. Its development has been described elsewhere[12]. It is based on the notion of features and can handle the eight following features and associated machining operations (Figure 2):

- face (face milling)
- slot (milling)
- holes (drilling, boring, reaming)
- counterbored holes (counterboring)
- side (milling)
- pocket (milling)
- thread (tapping)
- countersunk holes (countersinking)

ARCHITECTURE OF ICAPP

For each feature to be produced, the system checks the capability of the machine tool in use by searching through a database of available machines. It then selects the best cutting conditions based on the power of the machine tool, the material of the work piece and the tool which the system has selected. Based on surface finish information, the system generates the appropriate finishing operations. It should be noted that the system handles each feature discretly. Once all the features have been described, the system selects the best sequence for manufacturing the part based on manufacturing rules [13]. While the main part of the program is written in FORTRAN, this part of the program, called SEQUENCE, is an expert system written in LISP whose goal is to minimize work handling time while respecting manufacturability. At this stage, the system has generated a fully detailed and sequenced process plan for the part, including:

- operation type
- RPM
- tooling information
- feed
- depth of cut
- number of passes
- cutting speed
- width of cut
- machine to use

The program is ready to generate part programs if the user has specified this option. Currently, the input of the geometry information required for process planning and machining is carried out interactively. The system asks first for basic description of the feature required for determining the cutting conditions and selecting the tool. If the user wishes to generate part programs, he must enter additional geometrical information. The different modules which cater to the different types of geometry statements are shown in Figure 3.

Further development of the system will require automation of geometric and design information input. Initial work in this area has shown successfull results for prismatic parts, starting from a file in an IGES format and using the operator to select feature geometry on the terminal

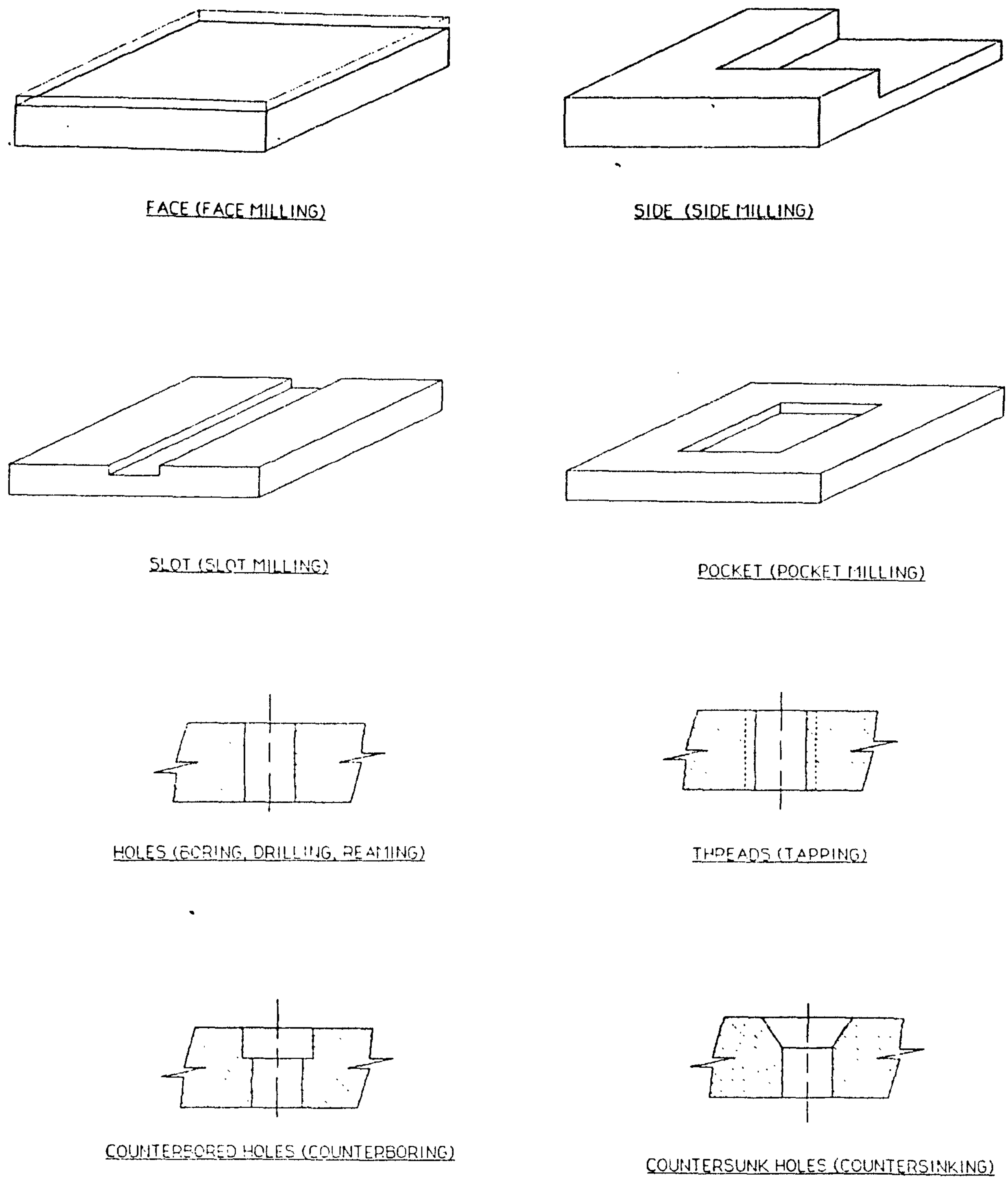


Figure 2: The features and associated machining operations handled by ICAPP.

and provisions for this mode of input are currently being implemented [14] (Figure 3). The literature offers interesting approaches to this problem. For rotational parts, Turbo-CAPP [15] uses a feature extraction module to identify geometric entities from a 2-D design drawing. Despite these advances, CAPP systems will require additional information such as tolerancing and surface finish, for which the coding is not standardized. The required information depends mainly on the capabilities of the process planning system and the generation of NC code. One promising area is the development of feature based CAD systems in which geometry as well as design information can be stored and referenced for easy retrieval by a CAPP system. One system, based on the Delta Volume to Remove method [16] starts from a blank workpiece and actually allows removal of volume as a manufacturing operation to generate the finished part. The features created would thus easily be available to a CAPP system. The automation of data input is a requirement for the development of CAPP, yet the ICAPP system as it is now is flexible enough to provide a testbed for generating part programs.

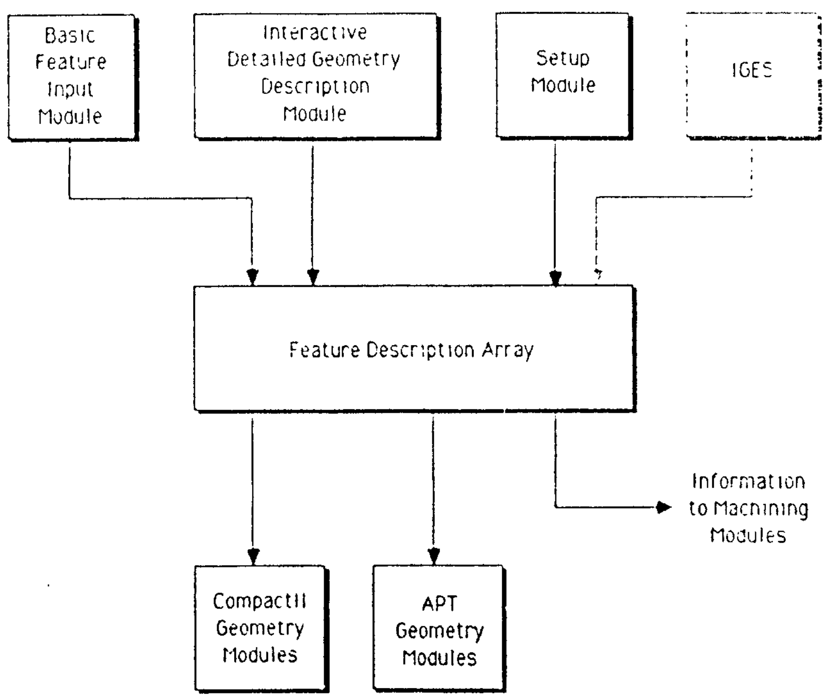


Figure 3: Handling of geometry.

GENERATING NC PART PROGRAMS

STRUCTURE OF AN NC PART PROGRAM

An NC part program can take many different forms depending on which level it is meant to be written for. At the machine controller level, it is a set of M and G codes which control the various functions of the machine such as spindle location, cutting conditions, coolant, etc. The advantage of using these codes is that the simpler ones have been standardized and make the system machine independent. However, most NC machines have their own set of codes for advanced functions. These codes invoke canned cycles which are optimum for that machine tool. It is therefore more advantageous to use higher level languages which are then post processed for a particular machine tool-controller combination and will make use of the particular advanced features built-in the machine tool. The ICAPP system can now generate part program in both COMPACT II and APT. The distribution of intelligence in ICAPP is such that it will take full advantadge of the advanced features of both systems and use its own logic when required. The structure of an NC part program in both of these languages consists of:

- setup statements
- geometry definitions
- tooling and machining instructions
- part program termination statements.

Accordingly, ICAPP generates part program statements in the same order (Figure 4).

STATEMENT GENERATION

The system described here provides a means of automatically generating a part program for each machine tool necessary to manufacture the part. Based on the machine tool code, the system retrieves the name of the post-processor for APT part programs and the name of the link for COMPACT II part programs. The setup statements are issued using information stored in the machine tool database as well as specific information on where that part will be positioned in reference to the machine.

The system then issues the geometry definitions by scanning through a database which contains definitions of the geometric elements associated with each feature. The geometric elements considered for holes are randomly positioned points as well as linear and circular patterns of points. For milling operations, the contours are defined using lines and circles. These definitions are related to the features through a drawing code for each feature. The proper format is chosen and the different subroutines account for the different types of geometry definitions (Figure 3). Once the geometry definitions are issued, the system scans the process plan for the part and extracts the required information to generate the tool changing and machining statements.

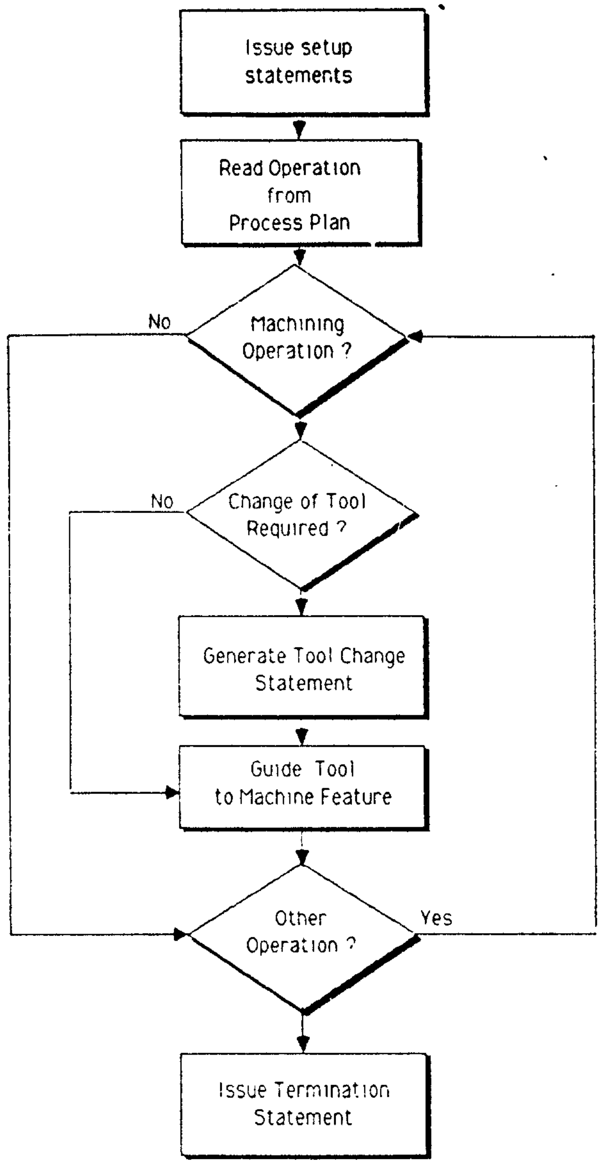


Figure 4: Generating the part program.

The output of the process plan includes a list of tools to be used on the machine tool. Those same tool numbers are used to specify the tool number to load to machine a given feature. If a change of face is detected during the scanning of the process plan, the tool change statement will contain an optional stop to enable the operator to change the orientation of the workpiece for non 5-axis machines. Once the tool is loaded, the appropriate cutting statements are issued.To do so, the previously generated process plan is scanned and machining operations are recognized. For each operation, the associated geometry statements are retrieved using the drawing code and are used to guide the tool in machining. Different algorithms are used for machining different types of features. The strategy employed is closely linked to the concepts used in the process planning function. For example, the process plan will generally specify three passes for a slot (one in the middle, and one on each side) if it cannot use only one. This is respected in the machining statements and appropriate stock values are calculated to perform this task. If side finish of the slot is required, the tool will stay in the slot and machine the sides, using again the finish cutting conditions calculated by the system.

Once a feature is completed, the tool is retracted from the depth of the feature and the system tends to the next operation. The part program is terminated once all the machining operations have been scanned. The tool is retracted to the tool change posititon and a termination statement is appended.

OUTPUT

The system has thus created a number of complete part programs, each in a different file for each machine required to manufacture the part. Currently, the system is capable of generating part programs in either APT or COMPACT II. The validity of the toolpath can be viewed on a graphic terminal once the file has been graphically processed. The file could also be post-processed for actual metal-cutting on a particular machine. Currently, training post-processors, not specific to any machine, are used. Using this system, a complete part program, using optimal cutting conditions and tools can be generated automatically within a few minutes. Current results show that the system is reliable for a workpiece which has clearly defined features. However, it must be noted that the system is limited to parts which have recognizable features and errors may occur when that limitation is not met.

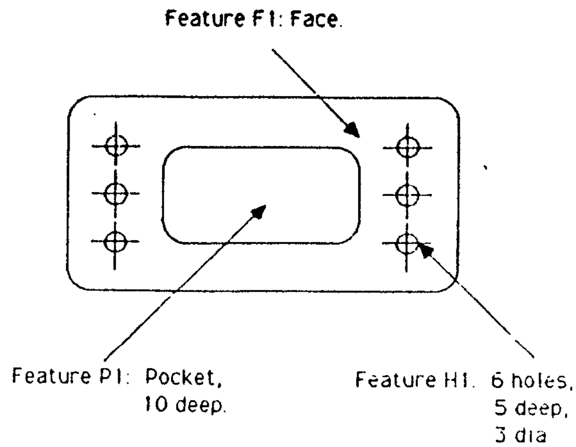
EXAMPLE

The following example demonstrates the capabilities of the system on a part which requires facing, pocketing and drilling of a set of holes (Figure 5). The features are described to the system and a sequenced process plan is generated (Figure 5).

The resulting part programs for both APT and COMPACT II, respectively are shown (Figure 6). Finally, the part program can be verified using plotting software (Figure 7).

CONCLUSION

Although current research is concentrating on the transfer of geometry and design information to CAPP systems, it is also important to develop the interface between CAPP and CAM. A system has been developed for prismatic parts which takes full advantage of the process planning features of the program and can generate working part programs. The development of such a system has shown the specifications which the CAD-CAPP-CAM interface must meet and has proven its versatility in handling both APT and COMPACT II.



PART NAME	= DEMO	MAT.NAME	= MILD STEEL	BATCH SIZE =	1.
PART NUMBER	= 1	MAT.SPECF	= EN 1A	DATE	= 07/02/87
DRAWING NO.	= 1	ASSEMBLY NO.	= 1	PLANNER	= CAPS LAB
M/T NUMBERS	= 20.				

OP	DRW.C	OP.DESCRP.	TOOL CODE	TOOL DIAM.	MT CODE	CUTTING CONDITIONS FEED	SPEED	RPM	DEPTH	WIDTH	PASS	S.T.	M.T.	H.T.	NOTES
1.		NEW M/T	0.	0.00	20.	0.00	0.00	0.	0.00	0.00	0.	1.00	0.00	0.00	
2		LOAD M/T FACE '1 '	0.	0.00	20.	0.00	0.00	0.	0.00	0.00	0.	0.00	0.00	1.00	
3.	F1	FACE MILL	1.	125.00	20.	179.44	1.06	160.	3.00	0.00	1.	0.00	0.24	1.00	
4.	P1	POCKET MILL (ROUGH CUT)	3.	4.00	20.	261.15	0.28	1352.	10.00	80.00	3.	0.00	0.46	1.00	
5.	H1	DRILL TO FINAL DIAM.	6.	3.00	20.	0.13	0.43	2726.	5.00	0.00	1.	0.00	0.10	1.25	
6.		UNLOAD M/T	0.	0.00	20.	0.00	0.00	0.	0.00	0.00	0.	0.00	0.00	1.00	
7.		INSPECTION	0.	0.00	20.	0.00	0.00	0.	0.00	0.00	0.	0.00	0.00	1.00	

TOTAL SET-UP TIME = 1.00 MIN

TOTAL MACHINING TIME PER COMPONENT = 0.81 MIN

TOTAL HANDLING TIME PER COMPONENT = 6.25 MIN

TOTAL TIME FOR BATCH = 8.06 MIN

FEEDS = MM/RPM FOR HOLE MAKING OPERATIONS
MM/MIN FOR MILLING
SPEEDS = M/SEC
DEPTH = MM
WIDTH = MM

Figure 5: A sample part and the generated process plan.

COMPACT II

```
MACHIN,L53
IDENT, DEMO ON M/C  20
INIT,METRIC
SETUP,    0.00X,    0.00Y,   40.00Z
BASE,   20.00XA,   20.00YA,   20.00ZA
DPT  1,     5.000XB,     5.000YB,     0.000ZB
DPT  2,     5.000XB,    45.000YB,     0.000ZB
DLN  1,PT  1,PT  2
DPT  3,    55.000XB,     5.000YB,     0.000ZB
DPT  4,    55.000XB,    45.000YB,     0.000ZB
DLN  2,PT  3,PT  4
DPT  5,    47.500XB,    36.000YB,     0.000ZB
DPT  6,    12.500XB,    36.000YB,     0.000ZB
DSET  1,RPT  5,S(PT  5),F(PT  6),  3EQSP,NOMORE
DPT  7,    12.500XB,    36.000YB,     0.000ZB
DPT  8,    12.500XB,    31.000YB,     0.000ZB
DPT  9,    12.500XB,    19.000YB,     0.000ZB
DSET  2,RPT  8,S(PT  8),F(PT  9),  3EQSP,NOMORE
DPT 10,    12.500XB,    19.000YB,     0.000ZB
DPT 12,    16.500XB,    18.000YB,     0.000ZB
DPT 13,    16.500XB,    32.000YB,     0.000ZB
DLN  3,PT 12,PT 13
DPT 14,    43.500XB,    18.000YB,     0 000ZB
DLN  4,PT  2,PT 14
DPT 15,    43.500XB,    32.000YB,     0.000ZB
DLN  5,PT  4,PT 15
DLN  6,PT  5,PT  3
DLN  7,PT  3,PT  2
DPB  1,RPT,PT 11;SPT,PT  1;CL,CONV
;S(LN  3),LN  4
;LN  5
;LN  6
;LN  7
;F(LN  4),NOMORE
DPT 16,     4.500XB,    25.000YB,     0.000ZB
DPT 17,    55.500XB,    25.000YB,     0.000ZB
ATCHG,TOOL 1,0GL, 125.00TD
MOVE, PT16
CUT, 179 44 MMPM, PT17
ATCHG,TOOL 2,0GL,   4.00TD
CUT, ENTRY( 1.2 ZB, PLUNGE), CLIMB, -  10.000 ZB,
;OVRLAP .01,1352 349MMPM,1352.349RPM, POCKET  1
ATCHG,TOOL 3,0GL,   3 00TD,118TPA, 0.13MMPR,2726.4RPM
DRL,SET 1,PT  7,   5.000DP
DRL,SET 2,PT 10,   5.000DP
HOME
END
```

APT

```
PARTNO DEMO
CLPRNT
MACHIN/HPUNCH,0
STPT=POINT/   0.000,   0.000,  40.000
MATREF=MATRIX/TRANSL,  20.000,  20.000,  20.000
REFSYS/MATREF
PT  1=POINT/   5.000,   5.000,   0.000
PT  2=POINT/   5.000,  45.000,   0.000
LN  1=LINE/ PT  1, PT  2
PT  3=POINT/  55.000,   5.000,   0.000
PT  4=POINT/  55.000,  45.000,   0.000
LN  2=LINE/ PT  3, PT  4
PT  5=POINT/    47.500,   36.000,    -3.250
PT  6=POINT/    12.500,   36.000,    -3.250
PAT  1=PATERN/LINEAR, PT  5, PT  6,  3
PT  8=POINT/    12.500,   31.000,    -3.250
PT  9=POINT/    12.500,   19.000,    -3.250
PAT  2=PATERN/LINEAR, PT  8, PT  9,  3
PT 12=POINT/  16.500,  18.000,   0.000
PT 13=POINT/  16.500,  32.000,   0.000
PT 14=POINT/  43.500,  18.000,   0.000
PT 15=POINT/  43.500,  32.000,   0.000
PT 16=POINT/     4.500,   25.000,     0.000
PT 17=POINT/    55.500,   25.000,     0.000
TOOL NO/ 1
LOADTL/ 1
CUTTER/ 125.000
FROM/STPT
FEDRAT/179.44
SPINDL/160.00
GOTO/ PT 16
GOTO/ PT 17
GOTO/STPT
TOOL NO/ 2
LOADTL/ 2
CUTTER/   4.000
FROM/STPT
SPINDL/ 1352.00
PL 1=PLANE/0,0,1,-   13.000
PSIS/PL 1
POCKET/  2.000,   1.000,   1.000,  261.15,$
  261.15,   0.000, 0, 3,$
PT12 ,PT 13$
,PT 15$
,PT 14
TOOL NO/ 3
LOADTL/ 3
CUTTER/   3.000
FROM/STPT
FEDRAT/ 0.13
SPINDL/ 2726.00
CYCLE/DRILL,5.25
GOTO/PAT 1
GOTO/PAT 2
CYCLE/NOMORE
GOTO/STPT
FINI
```

Figure 6: Part programs generated automatically by the system

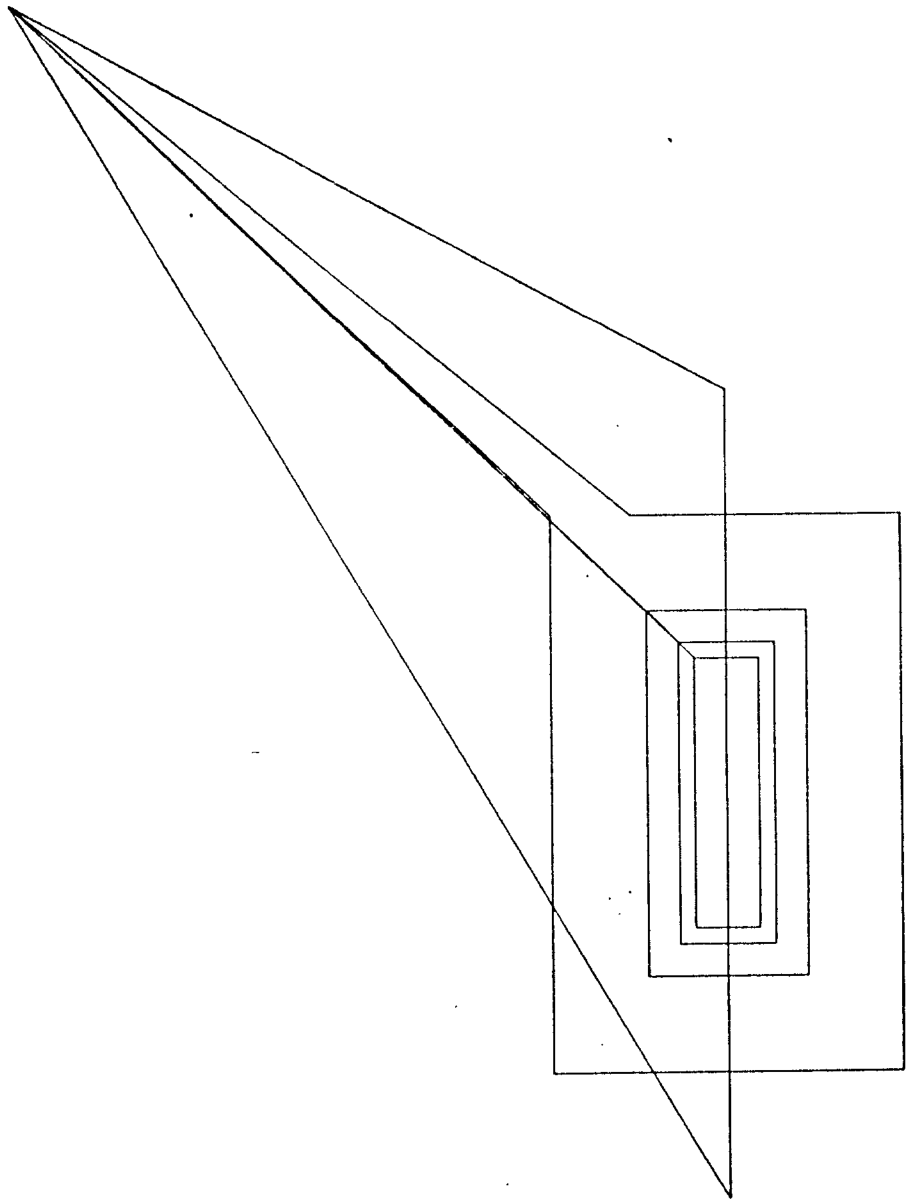


Figure 7: Plot of the part program generated in APT

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