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ORIGINAL ARTICLE

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# Parametric process planning based on feature parameters of parts

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**Abstract** This paper presents a model parametric process plan that is dependent on feature parameters of parts, and proposes a solution for the automated process planning of part families. Based on the parametric process plan templates for part families and the feature parameters of new parts, a prototype system is developed. First, parts are grouped into families considering their geometric or manufacturing similarities, and the parametric process plan template is pre-created for each family. Then, to plan the process of a new part, the system extracts feature parameters from its feature-based model and generates an a parametric process plan by searching the template library and solving related constraints. Finally, the system outputs the process plan sheets, if necessary. Although the system cannot creatively generate process plans for brand new parts, the system can meet two important requirements of the real industrial world to CAPP systems, that is good system performance and rapid response.

**Keywords** CAPP · Feature parameters · Parametric process plan

## 1 Introduction

The task of process planning involves a systematic determination of the detailed methods by which parts can be manufactured from raw materials into a finished product. It is an important stage that links design and manufacturing in an industrial organization. In general, it includes material selection, process selection, machine selection, tool selection, sequencing of operations, fixture selection, process plan documentation, and so on.

It has been nearly thirty years since the first CAPP system was developed under the sponsorship of Computer Aided Manufacturing International (CAM-I) in 1976. In this period, many CAPP systems have been developed and reported [1]. CAPP systems have been developed with either a variant approach or a generative approach. The variant approach relies on standard plans developed from previously manufactured parts: a new process plan is produced by retrieving the plan for a similar part and manually modifying it to fit the part at hand. In contrast, the generative approach creates new process plans automatically using knowledge about the manufacturing processes without referring to existing plans of previously manufactured components.

MIAPP, MITURN, MIPLAN/MIPREP, IPROS, TIDY, TOJICAPP, DOPS, ICAPP, and MICORPLAN constitute a representative example of variant CAPP systems [2–5]. In the variant approach, parts are first grouped into families based on their geometric or manufacturing similarities, and a unique code is assigned for each family based on group technology (GT) coding system. Subsequently, a standard process plan is generated for each family and stored in a computer. Whenever a plan is needed for a new part, a standard plan for a similar part is retrieved, and finally modified, if necessary. In most cases, an interactive modification is needed; however, this is tedious and labour-intensive. As a result, some errors are often produced because some of the operations or parameters of the process plan are not modified as they should be.

AUTAP [6], EXCAP [7], XPLAN [8], Turbo-CAPP [9], SIPP [10], KAPPS [11], KAPLAN [12], QTC [13], GENPLAN [14], and TVCAPP [15] are some representative examples of generative CAPP systems. In spite of enormous efforts, a general generative CAPP system has not been accomplished yet. The available automated CAPP systems mentioned above are mostly academic research-based or application-specific, and cannot be used in a real industrial environment [16]. All researchers have restricted their problem domains to handle only some aspects of such a system. Some considered only rotational parts, while others concentrated on prismatic ones only incorporating a very limited number of manufacturing features [17]. The generative approach produced a process plan using part representation, and its inference mechanism was based on metal cutting and human knowledge. It was very complex because the system must handle a large amount of process planning knowledge. The main diffi-

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culty here was the acquisition and representation of knowledge for a broad scope of implementation [18].

To trade off the advantages and disadvantages of a purely generative CAPP system and a variant CAPP system, some researchers have proposed a semi-generative approach to CAPP, which is basically a combination of the variant and generative methods. The aim of such a system is to reduce user interaction by incorporating standard operation sequences, heuristic rules and mathematical formula to the system [17]. COMPLAN [19] is such a system, and can be called a hybrid CAPP system. A hybrid CAPP system allows for a low degree of automation in the early stages and increases the degree of automation for which a knowledge base can easily be systematized. This characteristic avoids the long implementation time of the CAPP system resulting from the need to create a knowledge base.

In spite of enormous efforts, reported CAPP systems still have many limitations in real industrial environments. Rozenfeld and Kerry [16] presented a solution for automated process planning for parametric parts which allowed for a step-by-step introduction of the CAPP in a company. Here, in the early phases, there was no automatic function. And in the case of specific parts for which consistent knowledge is available, some automatic functions can be added to the solution later on. Therefore, The method is similar to that used in the aforementioned hybrid CAPP system.

The approach presented in this paper develops a parametric process plan dependent on the feature parameters of parts. In the case of a particular company, it is evident that for many items, the relationship of process plans and similar parts (or part family) are relatively fixed; but other items are determined by the feature parameters of parts, and as such are variable. Thus, parametric process plan templates can be used to depict the facts.

This paper is organized as follows. Section 2 provides the representation of feature parameters and the definition of the feature parameters set (FPS) of parts. The parametric process plan, including the mathematic model, the constraint knowledge for process parameters, and the parametric process plan template, is described in Sect. 3. The principles of proposed system are discussed in Sect. 4, followed by its implementation and an illustrative example in Sect. 5. Finally, conclusions are drawn in Sect. 6.

## 2 Feature parameters of parts

The feature of a part involves creating a 3D model of its geometric and manufacturing-related information (dimensions and tolerance). Here, feature parameters of a part are the geometric dimensions and tolerances (GD&T) for process planning purposes. In a feature-based 3D system, a part is composed of many features. Therefore, it can be described by the following:

$$\text{Part} = \left\{ f_0 f_1 \cdots f_i \cdots \right\} . \quad (1)$$

In this expression, $f_i$ is a feature of the part. The expression means that a part is made of a set of features. However, each feature has some feature parameters. For process planning purposes, the feature parameters of a part are GD&T. Subsequently, the feature is given by:

$$f_i = f_i \left( p0\, p1 \cdots pj \cdots \right) \quad (2)$$

where $pj$ is a parameter of the feature $f_i$.

All feature parameters are collected to form a feature parameters set (FPS). A new variant part can be obtained by changing the FPS. Here, there are two different cases:

1. With the change of FPS, the topological relationships of features are not changed. As shown in Fig. 1, the topological relationships of features are the same whether the diameter of hole is 8.5 or 15. Therefore, the two parts shown in Fig. 1 have similar process plans.
2. With the change of FPS, the topological relationships of features are changed. For example, consider the two parts shown in Fig. 2. When $a$ is equal to $b$, slot A and slot B unite one slot. In this case, the process plans of the two parts are dissimilar.

In this paper, similar parts, as discussed below, mean that they have the same topological relationships but different feature parameters when compared to the first case. In real industrial environments, most similar parts or parts that belong to a part family meet the first case. Therefore, this paper mainly discusses the first case. With respect to the second case, they can be grouped into different part families, and for each part family, all the parts meet the first case.

Based on these considerations, parts are grouped into families considering their geometric or manufacturing similarities, and are assigned a unique name for each part family according to its application. It is feasible to establish part families since the families or types of parts machined in particular company are limited.

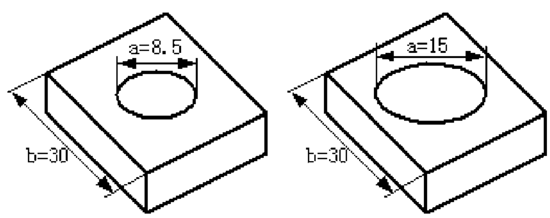



**Fig. 1.** Parts with same topological relationships

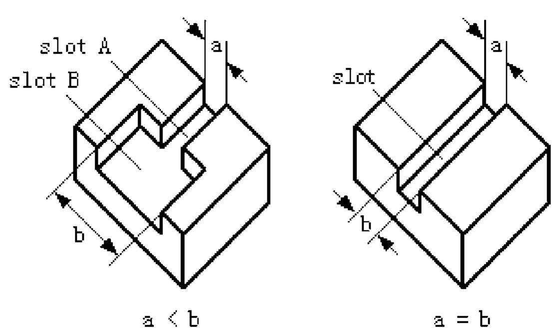



**Fig. 2.** Parts with different topological relationships

## 3 Parametric process plan

### 3.1 Mathematic model

In general, a detailed process plan includes the following:

- Sequence of process – links process/operation/activities together and builds a manufacturing sequence.
- Process – the set of manufacturing operations and other processes that are closely related to each other.
- Operation – manufacturing operations are assigned to a specific work area. This includes descriptions and cutting parameters, such as speed, feed, depth of cut and the number of passes.
- Activities – a further breakdown of the operations into activities with an associated duration time.
- Resources – resources are assigned to processes or operations. They refer to machining devices, tools, fixtures, workers, and so on.
- Consumed items – consumed items are complements of the product that are consumed during the manufacturing process.
- Workpiece – operation workpiece is a subset of the workpiece of the process. It includes the parts that are of interest to the operation.

Two similar parts and their processes are shown in Fig. 3. The process plans shown in Fig. 3 are only the major parts of a detailed process plans, but not the whole detailed process plans. All information of the two processes is same, with the exception of the diameter of the hole and its relative information.

In this case, a variable (e.g. $D$) is assigned to the diameter of the Hole, and the two process plans in Fig. 3 can be represented as Fig. 4. Normally, in practice of a particular company, it is quite evident that many items and their relationships of process plans for similar parts (or part families) are relatively fixed, but many other items are variable. Generally, the general form of a process plan can be given as fallows:

$$\text{proc} = \{\text{op}0\text{op}1\cdots\text{op}i\cdots\} \,. \tag{3}$$

In this expression, op$i$ is an operation, and proc is composed of sequential operations. Furthermore, for similar parts, $\text{op}_i$ is given by:

$$\text{op}_i = F_i \oplus V_i \tag{4}$$

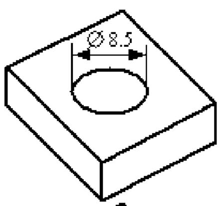
where $F_i$ are the fixed items; $V_i$, the variable items, can be written as

$$V_i = \{x_{i0}x_{i1}\cdots x_{ij}\cdots\} \,. \tag{5}$$

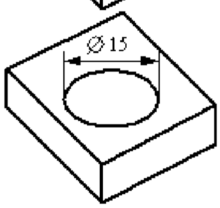
Here the variable $x_{ij}$ is called the parametric variable or process parameter. And proc in the Eq. 3, which includes parametric variables, is called a parametric process plan. From the representation above we know that the variable $x_{ij}$ is not only comprised of mathematic figures, but also characters.

### 3.2 Constraint knowledge for process parameters

Parametric variables can be assigned to any items and sub-items according to their process plans' relationships and the dependency of the similar part in a particular company. But how can we get the values for parametric variables in the parametric process plan? We determine the process parameter $x_{ij}$ in Eq. 5 by special knowledge dependent on FPS. This means that the parameter directly or indirectly lies on the FPS. For example, $X0$, $X1$, $X2$, $X3$, $X4$, $X5$ in Fig. 4 depend on some constraint knowledge, respectively, shown in Table 1.

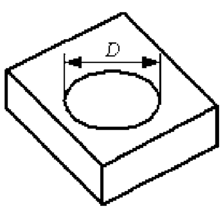



| Step | Process | Machine | Cutter | Cutting condition | Fixture |
|---|---|---|---|---|---|
| 1 | Drill Φ8.5mm through hole | Z4012 | Center drill, Twist drill(Φ8.5mm) | 1640 r/min, 0.1 mm/r | Vice |




| Step | Process | Machine | Cutter | Cutting condition | Fixture |
|---|---|---|---|---|---|
| 1 | Drill Φ15mm through hole | Z4016-A | Center drill, Twist drill(Φ15mm) | 1742 r/min, 0.1 mm/r | Vice |

**Fig. 3.** Similar process plans for similar parts




| Step | Process | Machine | Cutter | Cutting condition | Fixture |
|---|---|---|---|---|---|
| *X0* | Drill *X1* mm through hole | *X2* | Center drill, Twist drill(*X3* mm) | *X4* r/min, *X5* mm/r | Vice |

**Fig. 4.** Parametric process plan for Fig. 3

**Table 1.** Constraint knowledge of Fig. 4

| Parametric variable | Knowledge type | Knowledge |
|---|---|---|
| $X0$ | Rule | `if (D == 0) then`<br>`X0 = 0;`<br>`else`<br>`X0 = nCurrentIndex;` |
| $X1$ | Formula | $D$ |
| $X2$ | Searching from tables | `SEARCH MachName FROM MachTbl WITH D > minD AND D < maxD` |
| $X3$ | Formula | $D$ |
| $X4$ | Hybrid knowledge | `SEARCH minSpeed, maxSpeed FROM MachTbl MachName = X2;`<br>`X4 = minSpeed + (maxSpeed - minSpeed) *1/2;` |
| $X5$ | Formula | 0.1 |

Specifically, the case of step variable $X0$ in Fig. 4 is a special one in the parametric process plan. Normally, it represents the step number of process when its value is more than 0, where the process is cancelled if its value is 0. Thus, its value determines whether the process exists or not. As shown in Fig. 4, when the hole of the part does not exist ($D$ equals 0), the drilling process is not necessary. In this case, the topological relationships of features are changed. They can be grouped into different families as mentioned in Sect. 2. However, this model takes the special case into account for practical reasons.

Several kinds of constraint knowledge for process parameters are built into the system. They include as following.

#### 3.2.1 Formula

Usually, many parameters are determined by formula, for example, empirical formula and functional dependency. Here, formulas are dependent on FPS directly or indirectly as $X1$, $X3$ and $X5$, as shown in Table 1. Prasad et al. reported many formulas to optimize cutting parameters [20], and his work is valuable to the approach presented here. This kind of knowledge is explained and executed by the formula interpreter of the system.

#### 3.2.2 Rule

$X0$ shown in Table 1 is this kind of knowledge. The generic representation of this kind of constraint knowledge is as follows:

```
IF condition THEN
  Statement1;
ELSE
  Statement2;
```

where “condition” is relative to FPS. This kind of constraint knowledge is activated by the inference engine of the system.

#### 3.2.3 Searching from tables

Some parameters are obtained by searching from tables in resource databases given certain condition of the FPS. It can be represented as

```
SEARCH fldname FROM tablename WITH condition
```

The $X2$ shown in Table 1 is this kind of knowledge. In general, this kind of knowledge is useful to select machines, machining tools, fixtures, setups, and so on. For example, the machine database is shown in Table 2. The first column shows the name of machines, the second and third column correspond to the minimum and maximum drilling diameter, and the last three columns represent the rotation speed of the machine and power. The database searcher of the system applies this kind of constraint knowledge. And from Table 2, the database searcher can obtain the machine name for $X2$ of the process.

It is worth mentioning that multiple results of searching knowledge will be generated, but the rule knowledge can determine which result is the best one. Therefore, it is beneficial that searching knowledge is combined with rule knowledge. In fact, in order to get a process parameter, we usually need to combine several kinds of constraint knowledge, forming what is called hybrid knowledge. For example, $X4$ shown in Table 1 is determined hybrid knowledge.

In summary, all the constraint knowledge discussed above is dependent on FPS. Therefore, the process parameters are determined by FPS. And based on a company's practice, the constraint knowledge here is simple and local, while the knowledge domain is generic and broad.

### 3.3 Parametric process plan template

Researchers have found that parts that have similar geometry also have similar process plans [21]. In addition, the process plans of similar parts consist of fixed items ($F_i$) and variable items ($V_i$). Assigning a serial of variables to the variable items, the similar process plans of similar parts can be represented

**Table 2.** Part of machine database (MachTbl)

| Machine name (MachName) | Minimum drilling diameter (mm) (minD) | Maximum drilling diameter (mm) (maxD) | Minimum rotate speed (rpm) (minSpeed) | Maximum rotate speed (rpm) (maxSpeed) | Power (kW) (power) |
|---|---|---|---|---|---|
| Z4002A | 0.5 | 2 | 3000 | 8700 | 0.09 |
| Z4006C | 1 | 6 | 2300 | 11400 | 0.37 |
| Z4012 | 6 | 12 | 480 | 2800 | 0.55 |
| Z4015 | 10 | 15 | 480 | 2800 | 0.55 |
| Z4016-A | 12 | 16 | 335 | 3150 | 0.55 |

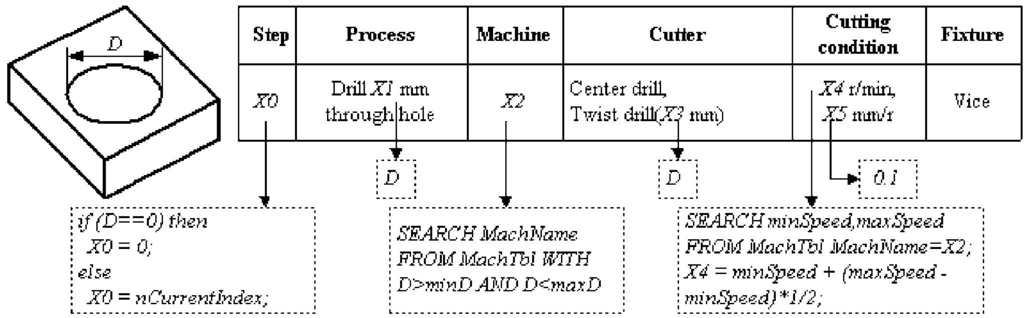



**Fig. 5.** Parametric process plan template for Fig. 3

as the same parametric process plan (described above). Simultaneously, similar parts can be grouped into one part family. Therefore, the parametric process plans for a part family should be same. So it is suitable that one parametric process plan be given to make the representation of process plans for a given part family uniform. In our work, this is called the parametric process plan template. It is significant and underlying principle for our proposed approach. The parametric process plan template for parts in Fig. 3 is shown in Fig. 5.

The process planning in a company does not start from scratch. For each part type (or family), many process plans are demonstrated to be sound in practice. Thus, it is possible to create a parametric process plan template for each type part based on the company's practice. There are many factors to be considered during the creation of a process plan template. These include the geometric configuration of the features, the location of the feature, the geometrical dependencies between the features, technological specifications (tolerances, surface finish and heat treatment) and the raw material. The steps of creating a parametric process plan template are as follows:

(a) finding a representative process plan for each type part from the available process plans;
(b) inputting the representative process plan into the system;
(c) defining parametric variables for the variable items of the process plan, as needed;
(d) assigning constraint knowledge to the parametric variables; and
(e) storing the information in a library as a parametric process template.

After templates for each part type are created, some problems may be encountered. For example, with the development of a company, a new part family will be manufactured; and/or with the development of a new manufacturing technology, a new process plan will be needed. However, these problems can be easily overcome by adding a new template for the new part family and updating the one for new manufacturing technology at any time.

## 4 Principles of the proposed system

It is commonly observed that in a particular company, for a particular part family, the machining processes and their sequences are rather fixed. Researchers have found that parts which have similar geometries also have similar process plans. With these characteristics, process plans for new parts can be obtained quickly by retrieving, and perhaps, modifying plans for similar parts via the GT categories [20]. Therefore, a variant approach seems suitable to establish a process plan. On the other hand, the variation in dimensions of the same part type may cause changes in the process plan, such as machine type, cutter size, fixtures, and cutting parameters. Therefore, modification is necessary. That is to say that if only a variant approach exists in a system, then the new process plan, which is derived from the standard process database, must be modified interactively. In this case, some errors will be produced. Some other intelligent technologies, such as formula calculation, rule-based inference, and searching information from tables must be incorporated in the local range in order to improve the degree of automation of the system. Based on these considerations, a new approach is proposed to develop a CAPP system. It contains the following steps:

(a) pre-establishing part families considering geometric or manufacturing similarities;
(b) pre-creating process plan templates including constraint knowledge for each part family;
(c) extracting the feature parameters from 3D model of a new part;
(d) generating a variant process plan for a similar part from the template library;
(e) solving the constraints in the parametric process plan template using the feature parameters extracted from 3D model; and
(f) outputting the process plan sheets, if necessary.

The overall functional block diagram of the proposed system is shown in Fig. 6. Although not highly generative, based on their machining resources and practice, different companies can easily adopt the proposed approach.

### 4.1 Extracting feature parameters

Process planning development requires product design data which includes geometric and technological information as input. The use of features is seen by many researchers as the key to integrate CAD and CAPP. In order to achieve this, some researchers have suggested that a single set of features be used for both design and process planning. However, designing parts using only manufacturing features is not a solution

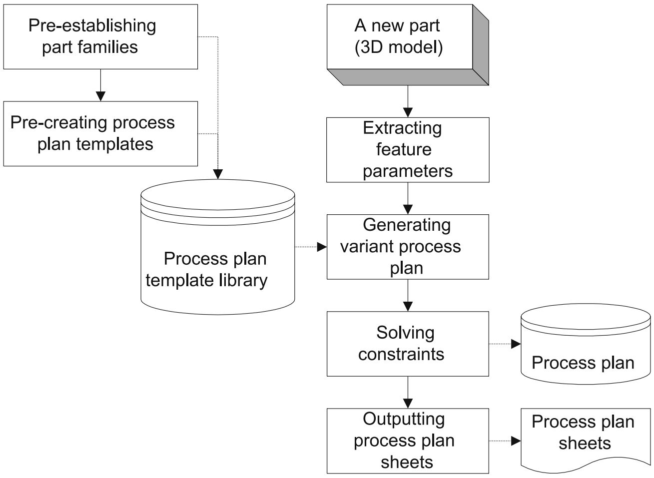



**Fig. 6.** The functional block diagram of the proposed system

to the interface problem since manufacturing features are not well suited for design, and designers usually are not familiar with the manufacturing processes. Other researchers suggested that design features could be mapped or converted to manufacturing features. This approach, however, overlooks the fact that one-to-one mapping between design and manufacturing features is not always possible, and physically non-realizable feature models may be generated. Since the early 1980s, a considerable number of researchers have attempted to interface CAD and CAPP using automatic feature recognition systems [17]. However, very few CAPP systems have automatic feature recognition interfaces. Currently reported feature recognition systems suffer from being unable to recognize complex or interacting features [22].

As mentioned above, generic feature recognition is difficulty. However, the positions, orientations and configurations of a feature are fixed for a particular part family. So here it is unnecessary to recognize the features of a part, and only the feature parameters are important. Therefore, the approach described here mainly concentrates on the extraction of the feature parameters (which are GD&T here) of a part for process planning purposes.

We know that the parametric function of 3D systems makes it possible to change the dimension values of a part at any time and drive the part to produce a new variant. In this research, the CAD models generated using Unigraphics NX, a commercial available software, are used as the input. In Unigraphics NX, UG expressions are powerful tools that make parametric design possible. By changing the expressions that control a specific parameter, designers can resize or reposition features on a model. UG expressions can supply various types of expressions such as arithmetic, conditional, geometric, Boolean operators and built-in functions.

UG expressions are so powerful that we can get the feature parameters through them. In the proposed system, the feature parameters are extracted by using the UG/Open API routine. At first, the system retrieves all expressions of a model. Then it evaluates the values of expressions and saves the values in a parameter file (a .txt file) later on. An example of extracting the feature parameters is shown in Fig. 7. It includes sketch dimensions, positioning dimensions, feature parameters, and form and orientation tolerances which are created by Geometric Tolerancing of Smart Model from the ASME 1994 Dimensioning and Tolerancing Standard. Figure 7a shows the CAD model, Fig. 7b shows the expressions dialog in Unigraphics NX, and the parameter file is shown in Fig. 7c. In the example, some meaningful names are assigned to parameters, and some constraints are added manually via expressions. Obviously, the parameter file includes the feature parameters (or GD&T) of the part for process planning. The proposed system will make use of the parameter file below.

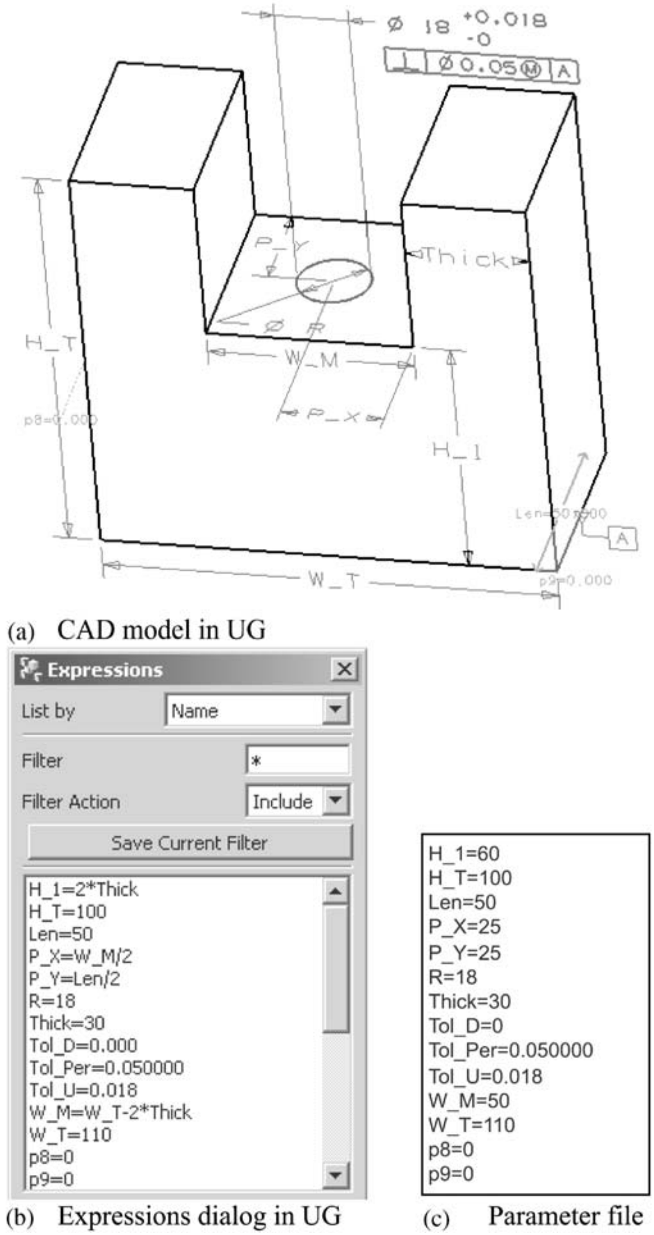



**Fig. 7.** Exacting feature parameters from CAD model

This approach extracts the feature parameters from a 3D model using Unigraphics NX expressions tools, but not interpreting or recognizing the features and their spatial relationships. Therefore, it is easy and practical.

### 4.2 Generating variant process plan

In this system, every part and every part family are assigned unique names. From the unique name of a new part, the system can get the part family which it belongs to, and a process plan template is pre-created for every part family. Consequently, a process plan template for a new part is easily retrieved from the template library according to its unique name. After that, a variant process plan, which is a copy of the process plan template, is generated. The structure of variant process plan generation is shown in Fig. 8.

### 4.3 Solving constraints

The variant process plan directly generated from the process plan template library is not a complete process plan; it includes some parametric variables determined by constraint knowledge. Thus, the system solves constraints and gets their values later on. As mentioned above, every parametric variable is connected to some special constraint knowledge dependent on the FPS of the part. Thus, the values of the parametric variables could be determined from the constraint knowledge. In this system, the formula interpreter, inference engine and database searcher are developed to solve the parameters. The flow chart of solving constraint knowledge is shown in Fig. 9.

It is possible that some parameters cannot be determined by any constraint knowledge in the system (as mentioned above), or by other systems or other real conditions. These parameters can be determined through interactive input. And yet in spite of enormous efforts to overcome it, the possibility cannot be excluded.

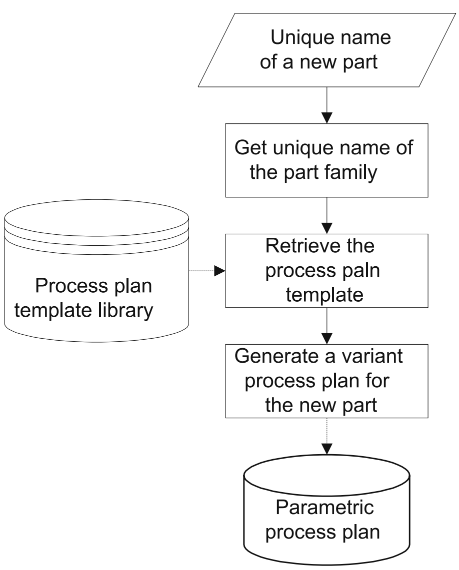



**Fig. 8.** Structure of variant process plan generation

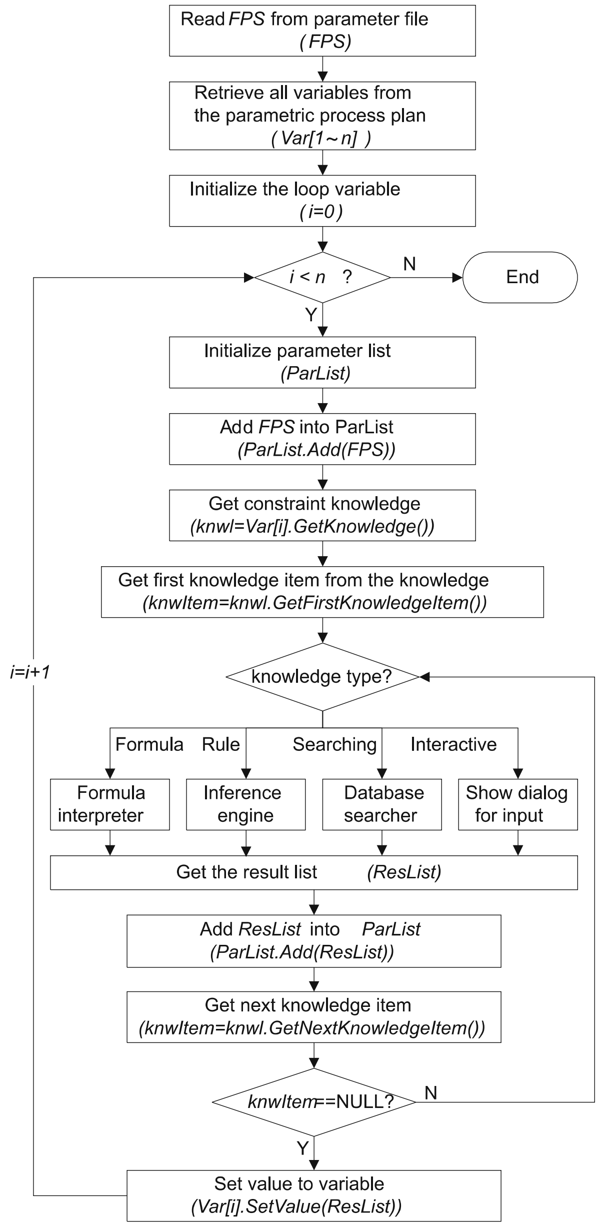



**Fig. 9.** Flow chart of solving constraint knowledge

As a system accepted by real industry, interactive input is necessary, but not of utmost importance. When interactive input is assigned to a parametric variable, the system shows a window for inputting the value.

### 4.4 Outputting process plan sheets

Finally, after the process plan has been completely generated, the system creates relative sheets to publish the process plan, if necessary. In the system there are some pre-defined templates based on XML/XSL technology, and the process plan sheets are printouts for workers and/or can be used to communicate with other partners outside the system.

## 5 Implementation and illustrative example

A prototype system named ParaCAPP, which is integrated with the three-dimensional CAD model, has been developed on a Unigraphics NX platform. The program is coded in C language using UG/Open API routines.

Figure 10 shows a straight connecting rod of a company in which automobile fittings are manufactured. It is a parametric part and has around twenty features, with an average of five parameters per feature. Thus, with almost 100 parameters, all the GD&T of the rod are hidden, and only geometrical bodies are shown in Fig. 10 in the interest of clarity.

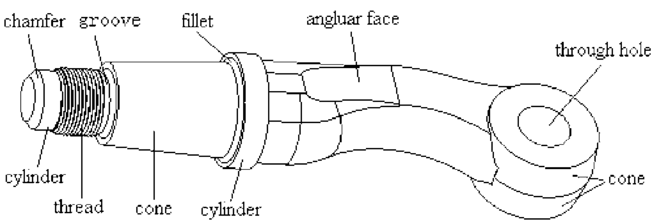



**Fig. 10.** An example of a straight connecting rod

The ParaCAPP interface (see Fig. 11) depicts the parametric process plan template of the straight connecting rod (as shown in Fig. 10). In the template, processes, sequence of processes, parametric variables, relative constraint knowledge and so on, are pre-defined as described above.

The system goal is to obtain detailed process plans (described in Sect. 3.1) with as little interactive modification as possible. In fact, the system generates the detailed process plans automatically for the rod using the approach presented in this work. Part of the process plan generated by the system for the manufacture of the rod is shown in Table 3. The straight connecting rod is manufactured from a forging component to a finished product.

It is worth mentioning that activities, workpiece illustrations, measuring tools, assisting tools and setups are not shown in Table 3. For a particular part family, they are considered relatively fixed and are defined in the plan template.

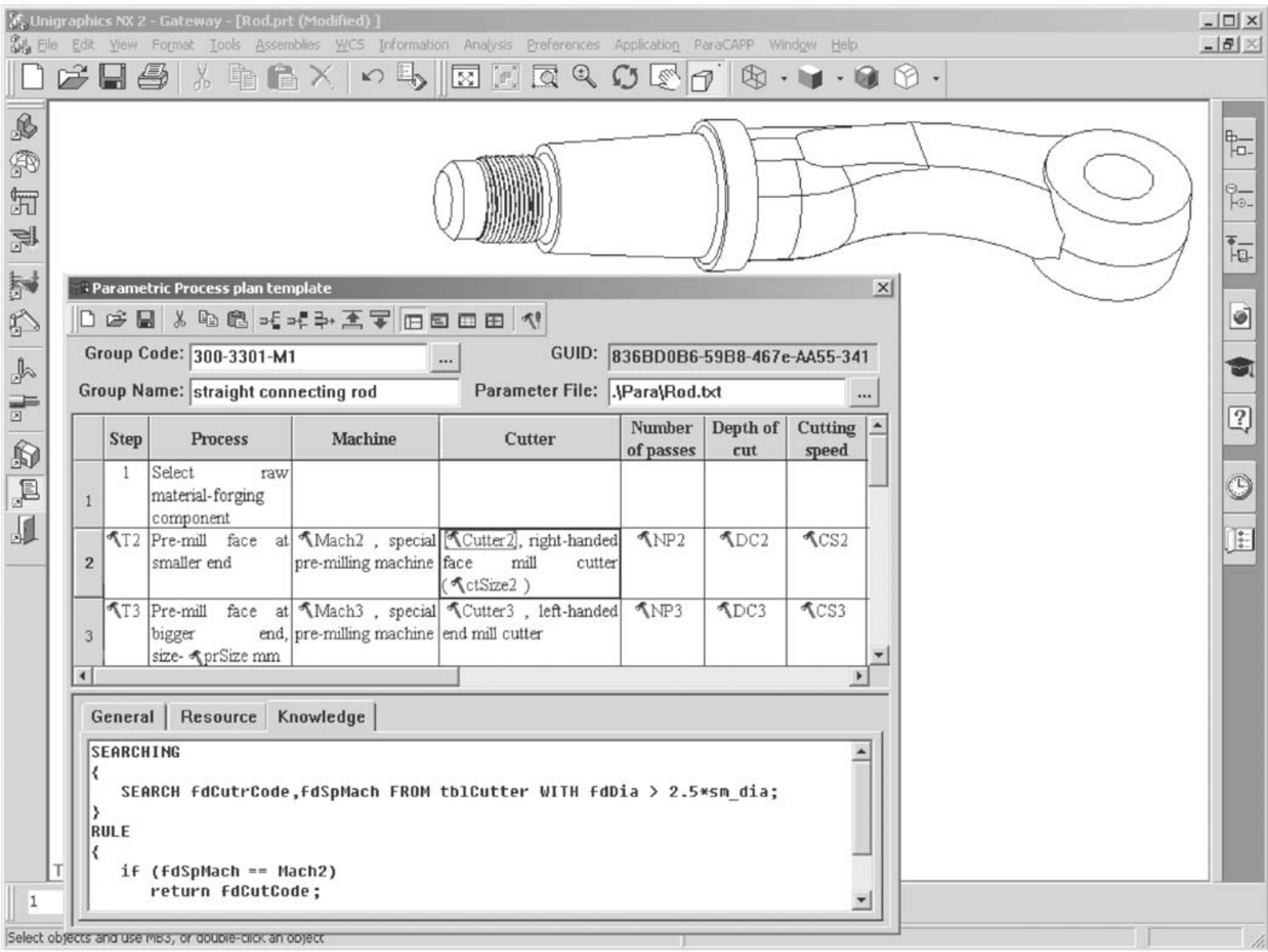



**Fig. 11.** ParaCAPP interface

**Table 3.** Part of the process plan for the straight connecting rod shown in Fig. 10

| Step | Process | Machine | Cutter | Cutting condition* | | | | | Fixture |
|---|---|---|---|---|---|---|---|---|---|
| | | | | NP | DC | CS | RS | FR | |
| 1 | Select raw material-forging component | | | | | | | | |
| 2 | Pre-mill face at smaller end | JQ-XZ002, special pre-milling machine | F2235.B.080.Z06.10, right-handed face mill cutter ($\phi$80) | 1 | 3 | 62.6 | 400 | 0.3 | 300330.M1-5201 |
| 3 | Pre-mill face at bigger end, size-232.9 ± 0.1 mm | JQ-XZ002, special pre-milling machine | F2241.B.050.Z04.12, left-handed end mill cutter | 1 | 5 | 100.5 | 400 | 0.3 | 300330.M1-5201 |
| 4 | Drill center hole for manufacturing | JQ-XZ002, special pre-milling machine | GB6078-85, center drill (B4/14) | 1 | 1.5 | 35.2 | 800 | 0.05 | 300330.M1-5201 |
| 5 | Rough turning handle | CK7812, numerical control lathe | PDJNL1616H11, cylindrical cutter | 1 | 1 | 71.6 | 600 | 0.2 | Lathe clamp |
| 6 | Finish turning handle, size-$\phi$24, $\phi 26.85^{0}_{-0.1}$, $\phi$38x$\varDelta$1:10 | CK7812, numerical control lathe | PDJNL1616H11, cylindrical cutter | 1 | 0.5 | 95.5 | 800 | 0.15 | Lathe clamp |
| 7 | Turning screw, size-M27x1.5-6g | CK7812, numerical control lathe | LSASR-1616M12, KC730 screw cutter | 4 | | 42.3 | 500 | | Lathe clamp |
| 8 | Mill faces of cone, size-30.5 ± 0.5 | X333, face milling machine | $\phi$200x25, rotatable face and side milling cutter | 1 | 3 | 62.8 | 100 | 25 | 300330.M1-5401 |
| 9 | Mill angle face, size-7°30′ ± 30′ | XQ5025B, upright milling machine | X203-63 Kr75, facing-type cutter | 1 | 4 | 39.6 | 200 | 25.5 | 300330.M1-5402 |
| 10 | Mill flat square | XQ6135, horizontal milling machine | $\phi$200x25, staggered tooth face and side milling cutter | 1 | 1.5 | 65.3 | 104 | 47 | 300330.M1-5403 |
| 11 | Drill bottom hole, size-$\phi$18.5 | Z5140B, upright drilling machine | GB1439-85, twist dill ($\phi$18.5) | 1 | 9.5 | 14.9 | 250 | 0.16 | 4-35 clamp |
| 12 | Reaming cone-shaped hole, size-$\varDelta$1:10 | Z5140B, upright drilling machine | 300330.M1-6201, $\phi$22 x$\varDelta$1:10 reaming cutter | 1 | 0.2 | 4.4 | 63 | 0.16 | 4-35 clamp |
| 13 | Heat treatment-harden to HRC55 | | | | | | | | |
| 14 | Grind out-cylinder of handle | ME1332A, grinding machine | SP600x50x305, grinding wheel | 10 | 0.25 | 35.7 | 72 | 0.02 | |
| 15 | Polishing and benching | | | | | | | | |

* NP: number of passes; DC: depth of cut (mm); CS: cutting speed (m/min); RS: rotate speed (r/min); FR: feed rate (turning: mm/rev or milling: mm/min)

## 6 Conclusions

Normally, the application scope of AI-based CAPP systems is restricted due to the difficulties involved with acquiring the necessary knowledge. Therefore, these systems usually work for a specific purpose. In this paper, we demonstrate that it is possible to develop a generic and automatic process planning system based on the characteristics of the problem being solved. In other words, we have limited the scope and definition of the problem in order to simplify the solution. In the practice of a particular company, many items and their relationships of process plans for a particular part family are relatively fixed. Hence, process plan templates can be applied to simplify them. On the other hand, parametric variables are used to stand for variable items of process plans, and a high degree of automation can be achieved by solving the constraint knowledge connected to the parametric variables.

In this paper, the idea and methodology demonstrates an approach to CAPP which is generic in nature. This system meets the requirements of a real industrial world that demands the best appropriate performance and the fastest return on investments. The advantages of the developed CAPP system are as follows:

1. It is flexible and expandable. A new process plan template for a new part family can be added and a different one for new manufacturing technology can be updated at any time.
2. It is easily transferable to different companies by simply keying in the process plan templates and the relevant constraint knowledge. And it can work when new machines or cutters are made available by only updating the databases. Thus, different companies can easily adopt the proposed system based on their machining resources and practice.
3. The system avoids errors generated by the traditional variant CAPP system and increases the degree of automation of process planning.

Since it pre-creates process plan templates for every part family in advance, the proposed system is useful to companies in which there are a few part types (part families), and a numerous parts in each part family. However, this approach is not suitable to companies that have a large number of part types (part families), and only a few parts in each part family. Another limitation of this approach is that it cannot creatively generate process plans for completely new parts.

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