8. DESIGN ASPECTS OF A PROCESS PLAN GENERATION SYSTEM

8.1 Introduction

This is the most important stage in process plan development. The process plan generation stage accepts the data from various other modules and produces the final output of the CAPP package. Implementation of this module needs an in-depth knowledge about the process planning technique and also it requires knowledge about Knowledge Based System (KBS), AI and Expert Systems. The process planning methods followed in the industries are extracted from the process planning experts and implemented in the form of decision logic, to generate the process plans. The activities in process plan generation includes selection of operations to be performed on the blank to realize the final part, sequencing of operations, machines, cutting tools required for each operation, and quality control operations.

8.2 Inputs and Outputs of the System

The data required for process plan, material requisition form etc. are generated as outputs by this system. The inputs and outputs for this system are given in the subsequent sections. The information flow regarding the inputs and outputs for the process generation system is shown in Fig. 8.1.
Parts model in Process Plan with
1. Manufacturing operations sequences
2. Quality control operations

Fig. 8.1 Information Flow in Process Plan Generation System

Fig. 8.2. Role of interfacing submodule
8.2.1 Inputs

i. From feature recognition module
   1. Part description - general information about the part
   2. Feature description - various features of the part with their dimensions, tolerances and surface finish

ii. From database module
   1. Information’s about machines like machine code, capability, and tolerance attainable
   2. Complete tool information like insert code etc.
   3. Workpiece details like, blank size, alternate material from Workpiece database.
   4. Cutting parameters like speed, feed etc.
   5. Inspection gauges etc.

8.2.2 Outputs

The outputs of this module are sent to centralized database for storage. The main outputs of this module are,
   1. Required raw material details
   2. The optimized process plan
   3. Quality control operations for the manufacture
   4. Resources lists

8.3 Structure of Process Generation System

The process generation system has been subdivided into the following modules:

- Interfacing
- Raw blank selection
- Feature sequencing
- Feature process correlation
- Process sequencing
- Quality control operations
- Output
Algorithms are developed for each of the planned action in different sub modules of the system. The structure of the system is shown in Fig. 8.3.

Fig. 8.3 Structure of Process Plan Generation System

8.3.1 Knowledge based process generation

The data required for process plan generation are part information, feature information, manufacturing data, details of reference and position / form tolerance for features present in the component. The process planning methods followed in the industries are extracted from the process planning experts and implemented in the form of decision logic, to generate the process plans. The methodology developed for providing feature information and the problems encountered are discussed. The selection of raw material; sequencing of features present in the component; selection of operations to be performed on the blank to realize the final part; sequencing of operations; machines required, cutting tools required for each operation; and selection of quality control operations are also discussed.

The output of the package is the process sheet containing the required raw material details, the optimized process plan, quality control operations for the manufacture, and resources lists.
The process plan generation module accepts data from various other modules and produces the final output of the CAPP package. The basic structure of the system is shown in Fig. 8.4. Separate modules have been developed for user interaction with knowledge base. Suitable screen has been developed for this purpose. If feature process correlation is done by knowledge-based approach along with a human in the loop who participates in some decision making while planning, the results obtained are found to be optimized. The structure of the system is shown in Fig. 8.4.

**8.3.2 Interfacing Submodule**

The tasks done by interfacing module is to interact with the ORACLE database and other modules of CAPP package. This sub module supports the information flow between feature recognition, database, and process generation modules. The role of interfacing submodule is shown in Fig. 8.2

**8.3.3 Blank Selection**

The selection of the blank for the given part is the first and foremost important task in computer aided process planning. The selected blank affects the selection of process, machine, tools and the operation sequencing. The size of minimum rectangular block (MRB) or bar stock will be given by feature recognition module. If the part geometry is complex (e.g., features like convex or concave curved surfaces, ribs) then, casting is
selected. In the case of rounds, billets etc the final selection of the raw material depends upon the user choice based on their availability in the ORACLE database.

The following factors and considerations will decide the selection of the raw material.

- The minimum size of blank or bar stock required.
- The geometry of the part.
- The material and its properties like hardness, strength, heat-treated condition, whether heat treatable or not.
- The quantity of the parts required and time permitted or available for the part production

The steps involved in blank selection are:

1. The dimensions of the part (Minimum rectangular block or bar stock) are increased by 5mm on all sides.

2. If the initial shape requirement is cylindrical, then search in the database for the bar with the required material and geometry of the part, otherwise, search for blank.

3. If the nearest size is available, select the block. Otherwise search for available circular rods of that material. The search for the bar stock is explained below:
   - Selecting the maximum of (X,Y,and Z) of part as length of bar stock
   - Selecting the second maximum of (X,Y,and Z) of part as diameter of bar stock

The algorithm developed for selection of raw material is shown in Fig 8.5.
Fig. 8.5 Raw Blank selection method
8.3.4 Sequencing of Features

The main criteria for arriving at the feature sequence are design tolerance and surface finish. The features with larger tolerance values are given priority over features with close tolerance values. This sequence may be sometimes over ridden by geometrical constraints of the feature. The flow chart for feature sequencing is shown in Fig. 8.6.

![Flow chart for feature sequencing](image-url)

**Fig. 8.6. Algorithm for Feature Sequencing**

8.3.4.1 Feature classification:

Machining involves normally removing the material, which is in some solid shape from raw material. A feature can be taken as a polygon extruded along some distance. The polygon when extruded will have two end faces and some shape faces (which are around the solid shape). When this object is removed from the Minimum...
Rectangular Block (MRB), the MRB gets some faces created or shared due to removal of that solid shape. The faces can be classified as

- Created end face (CEF)
- Shared end face (SEF)
- Created shape face (CSF)
- Shared shape face (SSF)

The classification of faces can be done by identifying the position of the face formed on the MRB. If the face formed due to material removal lies on one of the faces of MRB then it is considered as shared face, else it is created newly in the MRB, then it is considered as a created face. A feature can be classified based on the faces it created on the MRB. Here are two examples explaining the classification.

(i) Blind and through holes:

Holes can be considered as an object, which has two end faces and no shared shape faces. An object can be classified as blind hole if it has one shared end face (SEF); one created end face (CEF) and no shared shape faces (SSF), between the solid and the block. The through hole can be classified as having no CSFs, two SEFs and SSFs.

(ii) Rectangular slots:

Rectangular slot can be considered as an extruded polygon of 4 sides. This means that the solid is having 4 shape faces and 2 end faces. When this solid is removed from the MRB, if no shared end faces and one shared shape face are available, then it is a rectangular blind slot. If there are only one shared end face, one created end face and one shared shape face then it is a rectangular open slot. If two shared end faces and one shared shape face, then it can be considered as rectangular through slot.
Similarly, it is possible to classify the slots into different classes and subclasses depending upon the geometry of the created block as shown in Fig. 8.7.
The important External features are: (as shown in Fig. 8.8)
Sub classes: 1. Full or Blind 2. Straight or Variable 3. Combination of above

The important internal features are:
Sub classes
For Step: 1. Full or Blind 2. Straight or Angular 3. Combination of above
For Slot: 1. Full or Blind 2. Straight or Variable 3. Rectangular or Angle or V or T or Dovetail or Circle or Form 4. Combination of above.
For Circular Hole: 1. Through or blind or Round Bottom or Flat Bottom 2. Step 3. Count. Sunk or Count. Bore 4. Threaded 5. Tapered 6. Inclined 7. Comb. Of above.(Fig. 8.9)
The various features of Base plate are shown in Fig. 8.10.

**Fig. 8.10 Base Plate and its features**

8.3.4.2 Methodology for Feature sequencing

**Table 8.1** Input for Feature Sequencing sub module (For Base Plate)

<table>
<thead>
<tr>
<th>FEAT. NO.</th>
<th>FEATURE NAME</th>
<th>TOLERANCE (IT Grade)</th>
<th>SURFACE FINISH (N Grade)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Step_thro_rect 1</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>Step_thro_rect 2</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>Hole_thro 1</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>Hole_thro 2</td>
<td>11</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>Hole_thro 3</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>6</td>
<td>Step_thro_rect_fillet</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>7</td>
<td>Slot_thro_rect_fillet 1</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>8</td>
<td>Slot_thro_rect_fillet 2</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>9</td>
<td>Round</td>
<td>7</td>
<td>6</td>
</tr>
</tbody>
</table>
Table 8.2 Output from Feature Sequencing sub module (For Base Plate)

<table>
<thead>
<tr>
<th>Feature No.</th>
<th>Feature Name</th>
<th>Tolerance (IT Grade)</th>
<th>Surface Finish (N Grade)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Hole_thro 1</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>1</td>
<td>Step_thro_rect 1</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>Step_thro_rect 2</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>6</td>
<td>Step_thro_rect_fillet</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>7</td>
<td>Slot_thro_rect_fillet 1</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>8</td>
<td>Slot_thro_rect_fillet 2</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>9</td>
<td>Round</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>Hole_thro 2</td>
<td>11</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>Hole_thro 3</td>
<td>6</td>
<td>7</td>
</tr>
</tbody>
</table>

The input and output of feature sequencing sub module for Base plate are shown in Tables 8.1 and 8.2 respectively.

The steps followed for feature sequencing are:

1. First the features available from the interface sub module will be sequenced according to the order specified in the rough feature order format. DRDL process planners have followed this format. But there is no unique principle for standard order since order is basically a function of geometry of a part.

This order format gives following inferences.

- External features are preceded over internal features.
- Complex sub features precede simple sub features. Complex sub feature means which requires more operations and also more attention during realization of the same.
- Nonfunctional features should be in the last.

2. Ordered features are once again sequenced according to the tolerance grade and surface finish. If the tolerance of the features is same, then order will be based on surface finish.

3. But the geometry of some features will force to machine them before other features. Some features will force to be machined at the end/starting. For e.g., Hole on a slant
surface (as shown in Fig. 8.11 (i)) and Holes through and in a slot feature (as shown in Fig. 8.11 (ii)). In Fig. 8.11 (i) the hole and chamfer features are interacting with each other. The hole feature must be machined before machining the chamfer, to overcome the problem of drill sliding. Similarly from Fig. 8.11 (ii), to machine vertical hole, slot feature has to be machined first, but horizontal hole must precede that of slot to decrease the drill deflections during machining.

The Base plate component (as shown in Fig. 8.10) has a through hole feature at the center. This feature has to be machined first, even though the feature has close tolerance, because it is to be used as a reference for remaining features. Due to the complexity involved in determining these interacting features, the software is provided with an interactive session, which will extract precedence constraints on the features from the user. By considering these constraints we will get feasible feature sequence.
8.3.5 Feature Process Correlation (FPC)

Fig. 8. 12 Algorithm for Feature Process Correlation
Table 8.3 Output of the Feature Process Correlation submodule for Base Plate

<table>
<thead>
<tr>
<th>S.No</th>
<th>Feature Name</th>
<th>Process</th>
<th>Machine</th>
<th>Tool</th>
<th>Machining Face</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>End face</td>
<td>Facing</td>
<td>Center lathe</td>
<td>Turning tool</td>
<td>Bottom</td>
</tr>
<tr>
<td>2</td>
<td>Cylindrical</td>
<td>Turning</td>
<td>Center lathe</td>
<td>Turning tool</td>
<td>Cylindrical</td>
</tr>
<tr>
<td>3</td>
<td>Cylindrical step</td>
<td>Step Turing</td>
<td>Center lathe</td>
<td>Turning tool</td>
<td>Cylindrical</td>
</tr>
<tr>
<td>4</td>
<td>Cylindrical taper</td>
<td>Taper turning</td>
<td>Center lathe</td>
<td>Turning tool</td>
<td>Cylindrical</td>
</tr>
<tr>
<td>5</td>
<td>Fillet</td>
<td>turning</td>
<td>Center lathe</td>
<td>Form tool</td>
<td>Bottom</td>
</tr>
<tr>
<td>6</td>
<td>Holethro</td>
<td>Drilling</td>
<td>Center lathe</td>
<td>Centered drill</td>
<td>Bottom</td>
</tr>
<tr>
<td>7</td>
<td>Holethro</td>
<td>Drilling</td>
<td>Center lathe</td>
<td>Drill</td>
<td>Bottom</td>
</tr>
<tr>
<td>8</td>
<td>Holethro</td>
<td>Fine Boring</td>
<td>Center lathe</td>
<td>Boring bar</td>
<td>Bottom</td>
</tr>
<tr>
<td>9</td>
<td>Stepthro_rect</td>
<td>End milling</td>
<td>Vertical milling</td>
<td>T-MAX-AL-Router</td>
<td>Top</td>
</tr>
<tr>
<td>10</td>
<td>Stepthro_rect</td>
<td>End milling</td>
<td>Vertical milling</td>
<td>T-MAX-AL-Router</td>
<td>Top</td>
</tr>
<tr>
<td>11</td>
<td>Stepthro_rect</td>
<td>Slitting</td>
<td>Vertical milling</td>
<td>T-MAX-Q-Slitting cutter</td>
<td>Top</td>
</tr>
<tr>
<td>12</td>
<td>Stepthro_rect</td>
<td>End milling</td>
<td>Vertical milling</td>
<td>T-MAX-Ball nose end mill</td>
<td>Top</td>
</tr>
<tr>
<td>13</td>
<td>Slotthro_rect_fillet</td>
<td>Slotting</td>
<td>Vertical milling</td>
<td>End mill</td>
<td>Top</td>
</tr>
<tr>
<td>14</td>
<td>Slotthro_rect_fillet</td>
<td>Slotting</td>
<td>Vertical milling</td>
<td>T-MAX-Ball nose end mill</td>
<td>Top</td>
</tr>
<tr>
<td>15</td>
<td>Slotthro_rect_fillet</td>
<td>Slotting</td>
<td>Vertical milling</td>
<td>Side and face mill</td>
<td>Top</td>
</tr>
<tr>
<td>16</td>
<td>Round</td>
<td>Profiling</td>
<td>Vertical milling</td>
<td>Concave profile cutter</td>
<td>Top</td>
</tr>
<tr>
<td>17</td>
<td>Holethro</td>
<td>Drilling</td>
<td>Radial drilling</td>
<td>Cormant-delta-S-Drill</td>
<td>Bottom</td>
</tr>
<tr>
<td>18</td>
<td>Holethro</td>
<td>Centredrilling</td>
<td>Radial drilling</td>
<td>Center drill</td>
<td>Bottom</td>
</tr>
<tr>
<td>19</td>
<td>Holethro</td>
<td>Drilling</td>
<td>Radialdrilling</td>
<td>Cormant-delta-Drill</td>
<td>Bottom</td>
</tr>
<tr>
<td>20</td>
<td>Holethro</td>
<td>Boring</td>
<td>Jig boring</td>
<td>Fine-Boring-head</td>
<td>Bottom</td>
</tr>
</tbody>
</table>

The part and feature information will be input into the process generation module from the feature-sequencing module. This module decides the processes, machines, and cutting tools required for realizing each feature. The process selection submodule is one of the important sub modules of the CAPP. The rule-based approach is used in selection of processes for each feature. In this approach **IF...THEN... RULES** are used in process selection. Table 8.3 gives the output of the Feature Process Correlation submodule for Base Plate.
8.3.5.1 Factors considered in process selection

The following factors are considered for Process selection is

- Geometry of the feature
- Material type namely Blank shape, Material condition
- Material properties
- Dimensions of the feature
- Design tolerances of the feature
- Surface finish required
- Series of operations for each feature

For the implementation of feature process correlation (FPC), various programs are written to read the required general and numerical feature data. These data will be processed at appropriate functions to decide the suitable processes, machines and cutting tools. The standard text library will be called to get the operation details about each operation. The flow chart for feature process correlation is given in Fig 8.12. The various tasks involved in feature process correlation (FPC) can be classified into macro and micro-planning activities. Macro planning involves global level decisions of process selection, machine selection, and fixture selection. Micro planning comprises tool selection, process parameter selection and time&cost calculations.

8.3.5.2 Process Selection

Machine process covers the entire spectrum of conventional and non-conventional processes for both metallic and non-metallic materials. Currently, there are at least '112' machining processes, of which '67' can be classified as non-conventional. There are '17' hole-making processes possible, but only some of them are used in any industry. Basic machining processes include turning, drilling, reaming, boring, tapping, sawing, milling, broaching, grinding/honing/lapping/roller burnishing, ECM/LBM/ECM, LBM. Milling is probably the most versatile of all processes. It is used widely for external shape forming from the simplest flat surface to delicate surface such as a curved propelled surface. Broaching is lesser-used processes that are normally efficient when machining a large volume of metal from a 'flat & slotted'
workpiece. Because of high tool cost, broaching is typically a high volume production.

The process selection problem can be mainly divided into two sections. They are

(i) Technological aspect of manufacturing the component: Selection of a suitable process is based on technological features of the component.

Table 8.4 Tolerances and surface finishes attainable with different processes

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Process</th>
<th>Most suitable materials</th>
<th>Material removal rate (with MS)</th>
<th>Normal dimensional tolerance (mm)</th>
<th>Normal surface finish (micron)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Turning</td>
<td>Various machineable materials</td>
<td>21 cm³/hp.min</td>
<td>+/- 0.025</td>
<td>0.4 - 6.3</td>
</tr>
<tr>
<td>2</td>
<td>Drilling</td>
<td>Various machineable materials</td>
<td>300 cm³/min</td>
<td>+ 0.15, - 0.025</td>
<td>1.6 - 6.3</td>
</tr>
<tr>
<td>3</td>
<td>Milling</td>
<td>Various machineable materials</td>
<td>6000 cm³/min</td>
<td>+/- 0.05</td>
<td>0.8 - 6.3</td>
</tr>
<tr>
<td>4</td>
<td>Shaping &amp; Planing</td>
<td>Various machineable materials</td>
<td>10 cm³ / hp. min</td>
<td>+/- 0.13</td>
<td>1.6 - 12.5</td>
</tr>
<tr>
<td>5</td>
<td>Surface Grinding</td>
<td>All materials excluding soft materials</td>
<td>164 cm³/min</td>
<td>+ 0.00, -0.10</td>
<td>0.1 - 1.6</td>
</tr>
<tr>
<td>6</td>
<td>Chemical machining</td>
<td>All common &amp; nonferrous metals</td>
<td>Upto 0.0025 - 0.13 depth.</td>
<td>+/- 0.1</td>
<td>0.8 - 1.6</td>
</tr>
<tr>
<td>7</td>
<td>Ultra sonic machining</td>
<td>Hard, brittle, non conducting materials</td>
<td>30 – 4000 cm³/hr</td>
<td>+/- 0.025</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>Abrasive jet machining</td>
<td>Hard, heat resisting materials</td>
<td>1 cm³/hr</td>
<td>+/- 10% of stock to be removed</td>
<td>50% lower roughness than prior operation</td>
</tr>
<tr>
<td>9</td>
<td>Electron beam machining</td>
<td>Any material</td>
<td>0.05 - 0.12 cm³/hr</td>
<td>+/- 10% allowed on hole and slot dimensions</td>
<td>2.5</td>
</tr>
<tr>
<td>10</td>
<td>Electrical discharge machining (EDM)</td>
<td>Hardened materials</td>
<td>49 cm³/hr</td>
<td>+/- 0.05</td>
<td>1.6 - 3.2</td>
</tr>
<tr>
<td>11</td>
<td>Laser beam machining</td>
<td>Any material</td>
<td>0.4 cm³/hr</td>
<td>+/- 0.025</td>
<td>2.5</td>
</tr>
</tbody>
</table>
The technological features are

i. Feature geometry: This includes the type of feature, its sub class. The sub class may either a compound feature or the cross section of basic feature changes its shape along its length.

ii. Feature dimensions: The basic dimensions are like diameter (or width, height), length, angle, and inclination of axis and sub-feature dimensions.

iii. Material properties: The material type, its condition and properties like hardness, strength and machinability play an important role in the selection of manufacturing processes.

iv. Dimensional tolerances: This is the variation allowed in dimensions of feature. A numerical value in IT grade indicates the range of dimensional tolerances. A lower tolerance forces to opt for finishing operations.

v. Surface finish: This is smoothness of the feature, which is average distance between peaks and valleys on the surface of the feature. The surface finish is also a numerical value, which indicates the surface roughens in terms of N grade.

(ii) Economics aspect of manufacturing the component: Selection of a suitable process is based on economical features of the component and the manufacturing system i.e., speed of machining process, cost of machining process etc., but this will be considered after the technological aspect. The reason for this is that such aspects of manufacturing systems are very much depend on the environment in which the system is used.

Tolerances and surface finishes attainable with different processes are given in Table 8.4

8.3.5.3 Process selection for Circular Holes

(i) Guide lines for process selection for holes: While process planning for circular holes, the following rules have been considered

Before starting the hole making operation, machining should be done on the face or plane on which the hole is situated.

After machining, carry out the center drilling operation.
Whenever larger diameter holes i.e., more than 30mm, first start with the rough drilling a hole of diameter 2 to 3mm less, and then perform finish drilling or reaming or boring operation to get the required diameter. This is needed to avoid the deviation in hole dimensions and geometry due to over heating.

If the hole is stepped, consider it as two holes. If bigger diameter portion is on the face side, machine the basic hole first and then machine step. If the bigger diameter portion is inside the material then boring operation has to be done for it.

Boring provides positioning accuracy (i.e., concentricity) and also provides better surface finish than does drilling.

Threads can be taken as a subfeature for holes. Threading operation is the last operation to be done for that hole.

(ii) FPC Algorithm for circular holes

For feature process correlation of circular holes five parameters were considered. Each of these parameters requires some data or dimensions, which are explained below. The flow chart for process selection for circular holes is shown in Fig 8.13.

(a) Depth of hole: Check whether the hole is blind or through. The dimensions needed are the diameter, depth, and tolerance. The process selection can be visualized from Table 8.5.

(b) Subfeatures: Holes may be counter sunk, counter bored, inside stepped, or may be threaded. The dimensions needed are angle and vertical length for counter sinking. Depth and diameter for counter bored holes. Pitch, number of starts and thread length are required for threaded subfeature.

(c) Taper: Taper holes may be needed in some cases. The required dimensions for the tapered hole are height and angle.

(d) Inclination: Hole axis may be at some inclination to the plane. The data required for this type of hole is angle of inclination w.r.t machining face.

(e) Bottom geometry: Some blind holes may be having the flat bottom or round bottom. For round bottom hole bottom radius dimension is needed. Most of the holes will have chamfer at the hole face or at the steps. These types of chamfers are considered interactively while doing feature process correlation.
Table 8.5 Process selection for basic holes

<table>
<thead>
<tr>
<th>Ratio d/I</th>
<th>Dia(d) mm</th>
<th>IT 10</th>
<th>IT 9</th>
<th>IT 8</th>
<th>IT 7</th>
<th>IT 6</th>
<th>IT 5, IT 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;8</td>
<td>&gt;38</td>
<td>D+B</td>
<td>D+M+B</td>
<td>D+M+B</td>
<td>D+M+FB</td>
<td>D+M+IG</td>
<td>D+M+L</td>
</tr>
<tr>
<td>&lt;8</td>
<td>15&lt;d&lt;38</td>
<td>D</td>
<td>D+B</td>
<td>D+R</td>
<td>D+R</td>
<td>D+IG</td>
<td>D+IG+L</td>
</tr>
<tr>
<td>&lt;8</td>
<td>3&lt;d&lt;15</td>
<td>D</td>
<td>D+MD</td>
<td>D+MD</td>
<td>D+MD</td>
<td>D+MD</td>
<td>D+IG</td>
</tr>
<tr>
<td>&gt;8</td>
<td>&gt;3</td>
<td>DHD</td>
<td>DHD</td>
<td>DHD</td>
<td>DHD</td>
<td>DHD</td>
<td>DHD</td>
</tr>
<tr>
<td>&lt;20</td>
<td>1&lt;d&lt;3</td>
<td>EDM</td>
<td>EDM</td>
<td>EDM</td>
<td>EDM</td>
<td>EDM</td>
<td>ECM</td>
</tr>
<tr>
<td>&lt;20</td>
<td>0.15&lt;d&lt;1</td>
<td>Wire EDM</td>
<td>Wire EDM</td>
<td>Wire EDM</td>
<td>Wire EDM</td>
<td>Wire EDM</td>
<td>ECM</td>
</tr>
<tr>
<td>&gt;20</td>
<td>.03&lt;d&lt;0.15</td>
<td>EBM</td>
<td>EBM</td>
<td>EBM</td>
<td>EBM</td>
<td>EBM</td>
<td>EBM</td>
</tr>
<tr>
<td>&lt;20</td>
<td>&lt;0.03</td>
<td>LBM</td>
<td>LBM</td>
<td>LBM</td>
<td>LBM</td>
<td>LBM</td>
<td>LBM</td>
</tr>
</tbody>
</table>

Note: D - Drilling; M - Milling; B - Boring; FB - Fine boring; IR - Reaming; IG - Inside grinding; L - Lapping; MD - Micro drilling; DHD - Deep hole drilling; EDM - Electro discharge machining; ECM - Electro chemical machining; EBM - Electron beam machining; LBM - Laser beam machining

8.3.5.4 Process selection for Non-circular Holes

The Non-circular (NC) holes can be considered as either through (cut) holes or pockets. These holes can also be divided into various classes based on their shapes and variation of cross-section along depth. The process selection procedure has been devised by considering the various technological features of a component. The data and the manufacturing operations required for machining it are given in the following sections. The procedure is shown in Fig, 8.14.

i) Rectangular: The dimensions needed to realize this feature are width, height and depth. The manufacturing operations considered are drilling, end milling, fine milling, inside grinding and EDM.
Fig 8.13. Algorithm for process selection for circular holes
ii) Straight: The cross-section can be constructed with straight lines. Since there are various configurations in the construction of this shape, the inscribed circle diameter and depth are considered as dimensions. The processes considered are drilling, end milling, profile milling, form grinding and Wire EDM. The Wire EDM process is used when area of cross section of the hole is less than 5mm². This is also used for Alloy steel parts whose hardness is higher than 35 HRC.

iii) Curved: If the cross-section contains any curved shapes, then non-circular holes can be considered as curved class. The dimensions needed to realize the feature are inscribed circle diameter and depth. The Wire EDM process is used when the radius of the smallest curve in the cross section of non-circular hole is less than 4mm.

8.3.5.5 Process selection for Slots

Slots are classified into various classes according to the shape and variation of cross section along the length. The slots can be further divided into subclasses like blind or open.

(i) Guide lines for process selection: While process planning for slots, the following rules have been considered.

   - During rough machining operation, leave 1mm allowance in all sides of slot for finishing operation.

   - If the width of the slot is less than 4mm, then EDM operation has to be suggested.
     Irrespective of the tolerance and surface finish required on slot feature, the EDM operation has to be suggested when the perpendicularity between the edges of slot is essential.

(ii) Dimensions and processes for slots: The dimensions and the manufacturing processes needed for each of them is explained in following sections.

(a) Rectangular Slots

The rectangular slots can be further classified into open and blind slots.

Open: The parameters required for their interpretations are width and height. To realize open rectangular slot, face or end milling has to be done. If closed tolerances and finish are required then surface grinding operation follows milling.

Blind: The parameters required for its interpretation is width, height and length of slot. To realize open rectangular slot, end milling has to be done. If the tolerance and
surface finish requirement is high, mill 0.25 mm less on all sides and then surface grinding operation has to be carried out.

(b) T Slots:
Neck width, neck height, and bottom width and total height can interpret T slots. T-slot has to be machined in two stages. In first stage, rectangular slot of dimensions (neck width X total height) will be machined by end mill. In second stage T-slot milling cutter will machine the bottom portion. If close tolerance and finish are required, grinding operation follows.

(c) Angle Slots
The dimensions of angle, top width, and length can interpret Angle slot. The manufacturing processes are angle milling and grinding.

(d) Dovetail slots:
The dimensions of top width, bottom width, angle, height, and length can interpret the dovetail slot. Machining operations considered are milling and grinding. First, machine the rectangular slot of dimensions (top width X height) by end mill, then machine the angled portion by dovetail milling cutter. If close tolerances are required accommodate the grinding allowances in the earlier operations and surface-grinding operation has to be done.

(e) Form shaped slots
The machining of non-regular slots with form tools, the machining should be carried out as two operations: first, the machining should be carried out with the nearest standard tool (i.e. End mill) available and then the form tool should be used for finishing the slot.

8.3.5.6 Process selection for Steps
The dimensions of width, height, and length can interpret the step. The manufacturing operations used are shaping, milling and grinding. If the step is through, machining has to be carried out with face milling cutter. If the tolerance is close, then grinding has to be done. If it is a blind step, then end-milling operation can be used. Sometimes, bottom side of the step may be filleted. This feature can be realized by machining with ball end mill.
8.3.5.7 Process selection for Cut

A cut can be of any cross-section. The different classes and their manufacturing operations are given below

(a) Straight or Curved: In this straight class, the cross-sections can be drawn using straight lines. In the curved class, apart from the straight lines, some curved edges are also permitted. These two classes are taken into same class as they can be manufactured with conventional machines. The operations required are face milling, end milling, finish milling and grinding.

(b) Profile: If the cross section is of irregular shape, then its class can be considered as a profile. The manufacturing operations considered are end milling, profile milling on CNC Machining Center.

8.3.5.8 Process selection for Boss

The extended cylindrical portion from the machining face of a part is considered as boss feature. The boss may be varying cross section along its length. The dimensions needed are diameter of boss and boss length. The manufacturing operations considered to realize this feature are turning, grinding and EDM.

8.3.5.9 Process selection for Fillets

The fillets are modifying features, which do not change the geometry of work piece at all. Radius is the only dimension needed for this feature. There are two reasons for creation of fillet on part, which is either functional purpose or safety purpose. The manufacturing operations depend upon the purpose of the same. If it is for safety purpose, filing of the edge to the required dimensions will serve the purpose. If it serves some function, it has to be done exactly to the required dimensions, by the machine using the concave milling cutter or form tool for roughing and grind later.

8.3.5.10 Process selection for round

The round feature is entirely different from fillets. The dimensions of radius, angle and length can interpret the round feature. The manufacturing operation is end milling.
8.3.5.11 Process selection for Chamfer

The dimensions needed for realization of chamfer are horizontal, vertical distance from the edge and angle to horizontal plane. For large components, planing operation and for small components, shaping or milling operations are preferred.

Fig. 8.14. Algorithm for process selection for non-circular features
8.3.6 Machine Selection

8.3.6.1 Factors to be considered in machine selection

The selection of most appropriate machine tool for a specific component has always been a difficult task.

Optimum machine tool selection depends upon the following factors.

- The work dimensions and weight.
- The travel (or holding) limits of table or carriage (or chuck) of a machine.
- The axes configuration of a machine.
- The number of tool positions.
- Is the particular part best suited for a lathe or a milling machine application? i.e., shape of the part.
- Tolerance and surface finish achieved on feature elements.
- Magnitude of cutting forces developed during machining.
- Machine hour rate.
- Overheads.
- Availability of a machine.
- Availability of fixtures.
- Part / feature machining times.
- Batch size

8.3.6.2 Technical constraints of various Machines

The Table 8.6 summarizes some of the more commonly used machine capabilities. In practice, the variety of machines under each of the headings is so wide that the table can provide only the most basic comparisons.

(i) Turning machines: Applicability of various turning machines is described here. If the basic machined feature is boss and tolerance requirement is more than IT7, and then conventional lathe has been preferred. If the component is axisymmetrical, having holes, offset from the axis and parallel to the axis, then CNC turning center has to be suggested. If the component is heavy, prismatic and machined feature is axissymetric, and then vertical machining center has to be suggested. If component is either a big
and needs a large centric height or a missile cone shape, then copy turning is preferred over the other machines.

Table 8.6 Commonly used machines and their capabilities

<table>
<thead>
<tr>
<th>Criteria</th>
<th>SHAPING</th>
<th>MILLING</th>
<th>TURNING</th>
<th>DRILLING</th>
<th>GRINDING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table Movement</td>
<td>Linear</td>
<td>Rotating</td>
<td>Linear</td>
<td>Rotating</td>
<td>Rotating</td>
</tr>
<tr>
<td>Workpiece movement</td>
<td>Linear</td>
<td>Linear</td>
<td>Rotating</td>
<td>Static</td>
<td>Rotating or linear</td>
</tr>
<tr>
<td>Part detail</td>
<td>Flat surfaces; Slant surfaces</td>
<td>Flat, profile surfaces; Holes and pockets</td>
<td>External and internal diameters; radial flat surfaces</td>
<td>Holes</td>
<td>Diameters or flat surfaces</td>
</tr>
<tr>
<td>Part Size</td>
<td>Small to quite large 1m x 2m For larger parts use planer</td>
<td>Depends on machine; up to 1m cube is common but up to 2m cube is possible.</td>
<td>Depends on machine; 0.5mm to 300 dia is common but up to 2 mts possible</td>
<td>Up to 25 mm dia. is common, over about 60 mm normally turned.</td>
<td>From 0.5 mm dia. to approx. 1 m x 150 mm</td>
</tr>
<tr>
<td>Typical tolerance (mm)</td>
<td>0.03 is possible; 0.06 typical</td>
<td>0.01 is possible; 0.03 typical</td>
<td>0.005 is possible; 0.03 typical</td>
<td>0.03 is possible; 0.1 typical</td>
<td>0.003 and better</td>
</tr>
<tr>
<td>Surface finish</td>
<td>Medium (1.6) to crude finish (25)</td>
<td>Moderate (6.3) to very good (1.6)</td>
<td>Moderate (6.3) to very good (0.4)</td>
<td>Moderate; 3.2 is possible</td>
<td>Excellent typical 0.4</td>
</tr>
<tr>
<td>Relative cost</td>
<td>Low</td>
<td>Medium to high depending on M/C and tolerances</td>
<td>Low to very high depending on volume and tolerances machine</td>
<td>Normally low</td>
<td>Normally high</td>
</tr>
</tbody>
</table>

(ii) Milling machines: Milling machines are mainly classified into horizontal milling machines and vertical milling machines. The Table 8.7 summarizes the capabilities of these machines.
### Table 8.7 Capabilities of Milling Machines

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Horizontal milling machine</th>
<th>Vertical milling machine</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of tools that can be operated at a time.</td>
<td>Number of cutters in one spindle and mill at a time.</td>
<td>Two or more spindles holding only one tool by each spindle at its bottom end to mill at a time.</td>
</tr>
<tr>
<td>Milling operations to be performed</td>
<td>Slab milling, side milling, Angle milling, gear cutting</td>
<td>Face milling, end milling, T_slot milling, profile milling</td>
</tr>
<tr>
<td>Surface finish and cutting capacity</td>
<td>Less</td>
<td>Better surface finish and cutting capacity is 15 to 20% higher.</td>
</tr>
</tbody>
</table>

Universal milling machines are used are used to produce (taper) spiral grooves and spiral shapes of varying depth.

Copy milling machine is used for producing the irregular features like form slots and cuts.

(iii) Boring machines: Boring machines are designed for machining of large and heavy work pieces. These gives better surface finish and positional accuracy. The boring machines are classified as horizontal boring machines, vertical boring machines, deep hole boring machines, vertical jig boring machines. The vertical jig-boring machine is used for high precision work since it gives 0.002mm accuracy. The Table 8.8 summarizes the capabilities of horizontal boring machine and vertical boring machine.
Table 8.8 Capabilities of Boring Machines

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Horizontal Boring Machine</th>
<th>Vertical Boring Machine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of work to machined</td>
<td>Machining of small and medium sized irregular work may be suitable</td>
<td>Medium as well as large size of work can be machined</td>
</tr>
<tr>
<td>Fixing of work on Machine table</td>
<td>Difficulty to fix the work on smaller table and to feed either longitudinally or cross-wise</td>
<td>Very easy to fix the work on big horizontal table and to be rotated only in a vertical plane</td>
</tr>
<tr>
<td>Accuracy</td>
<td>Less accurate work, due to less rigidity of the machine and tool</td>
<td>Very accurate work is possible due to extreme rigidity</td>
</tr>
<tr>
<td>Operations</td>
<td>Boring, turning, facing, reaming, milling, grooving, etc.</td>
<td>Internal boring, taper boring machining of flat surfaces, shoulder turning, taper turning</td>
</tr>
</tbody>
</table>

(iv) Grinding machines: Grinding machines are mainly classified, according to the application, into two types. They are surface grinders and cylindrical grinding. Table 8.9 summarizes the capabilities and features of Grinding Machines.

(v) Unconventional machines. These machines are used when either the part hardness is very high (for e.g., steel hardness is greater than 35HRC) or feature size is very less than 2mm length/dia (or less than 5mm²). The Table 8.10 summarizes capabilities of various unconventional machines.
Table 8.9 Capabilities and features of Grinding Machines.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Centerless Grinding</th>
<th>Center type Grinding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of feature</td>
<td>0.1mm to 120mm</td>
<td>1.25mm to any size</td>
</tr>
<tr>
<td>Rigidity of the work holding and time</td>
<td>More rigid and less time required.</td>
<td>Less rigid required and more time required</td>
</tr>
<tr>
<td>required for holding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Machining time required</td>
<td>Less</td>
<td>More</td>
</tr>
<tr>
<td>Tendency of work deflection and chatter during operation</td>
<td>Very minimum</td>
<td>Reasonable</td>
</tr>
<tr>
<td>Accuracy for small size jobs</td>
<td>Very high (0.0008mm)</td>
<td>Comparatively less (&gt;1m)</td>
</tr>
<tr>
<td>Process suitable for</td>
<td>Production work</td>
<td>General purpose</td>
</tr>
<tr>
<td>Control of work size</td>
<td>Easy</td>
<td>Difficult</td>
</tr>
<tr>
<td>Grinding other than cylindrical surface I.e., flats, slots etc.</td>
<td>Not possible</td>
<td>Possible</td>
</tr>
<tr>
<td>Handling of different dia of work</td>
<td>Not so easy</td>
<td>Not so difficult</td>
</tr>
<tr>
<td>Constant wall thickness of the hollow work</td>
<td>Not possible</td>
<td>Possible</td>
</tr>
</tbody>
</table>

8.3.7 Cutting Tool Selection

8.3.7.1 Factors to be considered in tool selection

The selection of optimum cutting tool for a particular operation is based on the following factors.

- Type of machine used.
- Type and condition of part material.
- Blue print tolerances and surface finish.
- Batch size.
- Tools availability
- IF Tool is a Form tool THEN Surface finish up to N7 is feasible
Table 8.10 Capabilities of various Unconventional Machines.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>USM</th>
<th>ECM</th>
<th>EDM</th>
<th>LBM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic mechanism of material removal</td>
<td>Erosion by mechanical abrasion</td>
<td>Ion displacement</td>
<td>Vaporization by thermo-electric method</td>
<td>Vaporization</td>
</tr>
<tr>
<td>Application of various work materials</td>
<td>steel, titanium, plastic, ceramics</td>
<td>Steel, super alloys</td>
<td>Steel, aluminum, titanium, Refracteries.</td>
<td>Aluminum, steel super alloys, glass Titanium, plastics</td>
</tr>
<tr>
<td>Application according to the shape of work piece</td>
<td>Large holes; profile non circular holes</td>
<td>Precision, surface of revolution, grinding. Deep holes (L/D&gt;20); Contouring a surface.</td>
<td>small holes; (upto 0.05mm) Deep holes; (5&lt;L/D&lt;20) Pockets.</td>
<td>Shallow holes (L/D&lt;20) Micro holes (0.01&lt;D&lt;0.15) Shallow cuts</td>
</tr>
<tr>
<td>Application for machining</td>
<td>Drilling, trepanning, Slicing, Engraving</td>
<td>Deburring; Only to conductive materials; honing</td>
<td>Grinding, threading, helical gear cutting.</td>
<td>For very hard materials; mass micro machining</td>
</tr>
<tr>
<td>Accuracy</td>
<td>0.005mm</td>
<td>0.004mm</td>
<td>0.01mm</td>
<td>0.008mm</td>
</tr>
<tr>
<td>Surface finish</td>
<td>2 to 0.5mt</td>
<td>1.6 to 0.4mt $/mu $</td>
<td>3.2 to 0.8mt</td>
<td>6 to 0.8mt</td>
</tr>
<tr>
<td>Economics of processes</td>
<td>High metal removal efficiency low capital cost, tooling cost, power consumption cost</td>
<td>Very high capital cost, very low tool wear</td>
<td>Higher tooling cost, material removal efficiency and tool wear</td>
<td>Very low power consumption cost, very high metal removal efficiency, very low tool wear</td>
</tr>
</tbody>
</table>

8.3.7.2 Cutting tool materials

Cutting tools are available in four basic material types. They are high-speed steel, Tungsten carbide, ceramic, and diamond. The type of tool should be carefully chosen. The applications and the corresponding tool materials are given below.

i) High speed steel (HSS) -- Mild steel, Aluminum, and other non-ferrous alloys.

ii) Carbide tools -- Steels, Stainless steels, High silicon aluminum's, and exotic metals.
iii) Ceramics -- *Hard* steels and exotic metals.

iv) Diamonds -- High melting point material alloys, ceramic metals and composites.

### 8.3.7.3 Tooling for Hole operations

i) Drilling -- Center drill; Tapered shank twist drill; Spade drill

If a hole tolerance is closer than 0.8 mm, a secondary hole operation should be used to size the hole such as boring or reaming. Large holes (40<d<60mm) are sometimes produced by spade drills. The flat blades allow good chip flow and economical replacement of the drill tip.

When drilling hard materials, cobalt drills (HSS with Cobalt added to the alloy) are used.

ii) Reaming -- Straightened fluted reamer; Spiral fluted reamer. These may be again classified as tapered and straight.

Reaming will hold a tolerance of 0.05 mm easily. Spiral fluted reamers produce better surface finishes than straight flutes, but are more difficult to resharpen.

iii) Boring -- Inserted carbides are used for large holes, whereas brazed and solid carbides are used for small holes.

iv) Taping -- Standard machine screw taps: These are used especially when tapping blind holes.

Spiral pointed taps (known as gun taps): These are preferred for through hole operations.

High spiral taps: These are used for soft stringy material such as aluminum.

### 8.3.7.4 Tooling for milling operations

The milling cutters are basically classified into end mills and face mills. Another way of classification is solid and inserted type. Inserted end mills are available from 0.5
inch to 3.0 inch diameter and solid end mills are available from 0.032 to 2.0-inch diameter, in 2 or 4 flute. Solid end two-flute mill cutter with their deeper gullets is well suited for roughing operations. Solid end four flute mill cutter is used for finishing operations. Inserted end mills are preferred for CNC applications. Face mills are designed to remove large amount of material from the face of the work pieces. Face mills are available in sizes from 2.0 inch to over 8.0 inch in diameter. Plunge and profile inserted mill cutter is used to mill the complex cut shapes. U - max end mill is suitable for steel alloys and titanium alloy materials, but not that much suitable for aluminum alloys. Mean while this is suitable for slots, steps where as not that much suitable for non-circular holes. Drilling end mill is suitable for non-circular holes. Chamfering end mill is suitable for slot and step type features. Round insert end mill is suitable for curved cut features.

8.3.8 Part Material Properties – Operation Selection

The material type and its properties plays an important role in the selection of manufacturing processes for part features. The material properties to be considered mainly, are tensile strength, material hardness, and machinability. The other minor properties to be considered depends upon the application of that part, which are mainly thermal properties, and electrical properties. The materials used for DRDL components are classified into five groups in order to incorporate rule based knowledge in the system for process selection of features. They are.

1. Aluminum and its alloys
2. Steel and its alloys
3. Super alloys
4. Titanium and its alloys
5. Refractories & Composites.
8.3.8.1 Properties and Machinability

(i) ALUMINUM ALLOYS:
@ Poor machinability in annealed / manufacturing condition.
@ Good machinability in tempered / precipitated condition.

(ii) STEEL AND ITS ALLOYS:
@ Material hardness is less than 22HRC, machinability is better
@ Material hardness is in between 22 and 32HRC, machinability is good
@ Material hardness is in between 32 and 42HRC, machinability is poor
@ Material hardness is greater than 42HRC, machinability is worst

8.3.8.2 Guidelines related to material property:

i) Heat-treat the material initially if required.

ii) If possible maximum material removal before heat treatment by keeping allowances for finishing operation.

iii) Minimum material removal by grinding / other finishing operations after heat treatment.

iv) If parts are having hardness more than 35HRC, unconventional methods are generally used. But if the parts are heat treatable to a conventional range, it is better to go for heat treatment.

8.3.8.3 Heuristic rules related to material property

- IF material is Aluminum THEN Turning is preferred over Grinding
- IF process is Lapping THEN forged work piece should be used but extruded work piece never to be used
- IF Material is composite THEN Polycrystalline coated Diamond tool to be used but HSS, carbide tools not to be used.
- IF component is Missile Nosecone THEN copy-turning machine is preferred over other machines.
- IF Material is FRP (Fiber Reinforced Plastic) THEN Tool material should be either carbide or coated HSS. Feed/speed parameters should be constantly monitored surface finish grades up to N7 is only possible.

- IF material is Ferrous THEN tool material should be CBN and never use Diamond

- IF material is Titanium THEN min. depth of cut should be 1mm, low cutting speed, positive tool rake angle, sharp tools, high feed rates, no dwell periods, flood cooling etc., to be ensured.

- IF Material is Al alloy THEN heat treatment should be done only once for the whole process sequence/usage of high speeds is also recommended.

- If Material is Tungsten THEN spark EDM with Graphite electrode to be used under condition that the finish is not a criterion for acceptance.

- IF Material is soft and has a sliding function THEN Lapping should not be done

- IF Tool material in Diamond THEN machine should be very rigid and hence precision class machines with high speeds are preferred.

- IF work piece is cast THEN ultrasonic testing should not be done

- IF work piece is forged THEN radiographic inspection is feasible

- IF Material is a MMC (Metal Matrix Composite) THEN machine should be EDM/WJM and maximum feasible surface finish is N6.

### 8.4 Manual Input

To get optimised process plan we need some more details like geometrical tolerances, references, positional/form tolerances. Presently Solid Models do not have an acceptable method of representation of the above. So these things have to be inputted manually. For this input screen is developed and shown in Fig.8.15. Also provision has been made to enter the Grinding Allowance because it will vary from industry to industry and feature to feature.
The manufacturing processes, tools and machines are selected considering the part material properties, feature, feature class type, geometrical dimensions, tolerances, references, positional/form tolerances and surface finish. The selection has been made by two methods. One is without user interaction with Knowledge Based System (KBS) and another one is with user interaction with KBS. Feature process correlation is done by knowledge based approach along with a human in the loop who participates in some decision making while planning, the results obtained are optimized. The Fig.8.16 depicts the user interface screen, which interacts with the Knowledge Based System (KBS).
8.4.1 Part and Feature Information

Part and Feature information consists of part and raw material details and base feature name, sub feature name and related information is stored in ORACLE database, which is opened for new part in manufacturing industry.

8.4.1.1 Part Information

i. WORK ORDER: This variable specifies the work order for new part.

ii. JOB NUMBER: This variable specifies the job number for new part.

iii. NUMBER OF ITEM: This variable specifies the total number of item present for above job number.
iv. PROJECT NAME: This variable specifies the name of the project opened for above work order.

v. PROJECT GROUP: This variable specifies the project group working for above work order.

vi. START DATE: This variable specifies the starting date of the project.

vii. FINISH DATE: This variable specifies the completion date of the project.

viii. ITEM NUMBER: This variable specifies the item number/code for above job number.

ix. ITEM DESCRIPTION: This variable specifies the description or name of the item for above item number/code.

x. DRAWING NUMBER: This variable specifies the drawing number for the above item number/code.

xi. QUANTITY REQUIRED: This variable specifies the required quantity in terms of number for manufacturing or assembly purpose.

xii. QUANTITY ISSUED: This variable specifies the quantity issued in terms of number for producing the above item number/code.

xiii. ASSEMBLY NUMBER: This variable specifies the above item number/code belongs to this assembly.

xiv. PROCESS PLANNER: This variable specifies the name of the process planner who is involved in process planning of this item.

 xv. RAW MATERIAL: This variable specifies the name of the raw material required for above item.

 xvi. RAW MATERIAL CONDITION: This variable specifies the initial condition of the raw material.

 xvii. SHAPE: This variable specifies initial shape of the raw material.

 xviii. WIDTH/DIAMETER: This variable specifies the width of raw material if it is a prismatic component or diameter of raw material if it is a cylindrical component.

 xix. HEIGHT/DIAMETER: This variable specifies height of raw material if it is a prismatic component.
xx. LENGTH: This variable specifies the length of raw material.

8.4.1.2 Feature Information

a) GENERAL DETAILS
   i. SERIAL NUMBER: This variable specifies the serial number of feature, which starts from 1.
   ii. BASE FEATURE NAME: This variable specifies the name of the base feature. Select it from list box.
   iii. SUB FEATURE NAME: This variable specifies the name of the sub feature, which is based on base feature name. Select it from list box.
   iv. FACE: This variable specifies the face, on which the feature is located.

b) DIMENSIONAL DETAILS
   v. TOTAL NUMBER: This variable specifies the total number of dimension required for each sub feature. This will be displayed automatically based on sub feature name.
   vi. DIMENSION NAME: This variable specifies the name of dimension for above sub feature. Select one by one for modifying or inserting other values.
   vii. VALUE: This variable specifies the dimensional value required for each dimension name.
   viii. UPPER TOL: This variable specifies the upper tolerance for the dimension.
   ix. LOWER TOL: This variable specifies the lower tolerance for the dimension.
   x. TOTAL NUMBER: This variable specifies the total number of references required for sub feature.

c) REFERENCE DETAILS
   xi. SERIAL NUMBER: This variable specifies the serial number of reference, which starts from 1.
xii. REFERENCES: This variable specifies the reference face or others from which the feature is located.

xiii. VALUE: This variable specifies the value of reference dimension required for each reference.

xiv. UPPER TOL: This variable specifies the upper tolerance for the dimension.

xv. LOWER TOL: This variable specifies the lower tolerance for the dimension.

d) FORM TOLERANCE

xvi. TOTAL NUMBER: This variable specifies the total number of form tolerance required for sub feature.

xvii. FORM REFERENCE: This variable specifies the form reference face or datum to fulfill form tolerance.

xviii. FORM TOL: This variable specifies the form tolerance for that feature.

xix. VALUE: This variable specifies the value of the form tolerance

e) SURFACE FINISH

xx. TOTAL NUMBER: This variable specifies the total number of form tolerance required for sub feature.

xxi. SERIAL NUMBER: This variable specifies the serial number of surface finish, which starts from 1.

xxii. NGRADE: This variable specifies the surface finish N Grade required for that feature.

8.4.1.3 Standard Text File Format

The details mentioned in the previous section are stored in a text file in the format detailed below:

\[
\text{PART\_START} \\
\text{Work order No} \\
\text{Item No}
\]
Item Description
Raw Material
Raw Material Condition
Dimensions

**FEATURE_START**

<table>
<thead>
<tr>
<th>Serial No</th>
<th>Base Feature</th>
<th>Sub Feature</th>
<th>Face</th>
</tr>
</thead>
</table>

**DIMENSION_START**

- No of required Dimensions
- Dimension Name1 | Value1 | Tolerance1
- Dimension Name2 | Value2 | Tolerance2
- . . .
- . . .

**DIMENSION_END**

**REFERENCE_START**

- No of required References
- Reference Face1 | Value1 | Tolerance1
- Reference Face2 | Value2 | Tolerance2
- . . .
- . . .

**REFERENCE_END**

**FORM/POSITION_START**

- No of required form/positions
- Form/position tolerance1 | Reference1 | Value1
- Form/position tolerance2 | Reference2 | Value2
- . . .
- . . .

**FORM/POSITION_END**

**SURFACEFINISH_START**

- No of required surface finish
- N grade

**SURFACEFINISH_END**

**FEATURE_END**

PART_END.
The Fig 8.17 shows the file generation module. This module generates the input file for process generation module. The input to be given for this module is workorder number, job number, item number and the path in which the generated file has to be stored. After giving the above details as input, the press of the Generate file button creates the file and stores it in the specified path. The exit button takes the control back to the input module. This facility helps in creating the part and feature information file for different components.

The software reads the input file and based on the decision rules incorporated, for the specific feature and tolerances, the appropriate manufacturing process is identified and the machine and tool required for manufacturing that feature are selected. Here, the user is provided with an option to either use the process generated by system based on the decision rules incorporated or he can interact with the system to give his own suggestions regarding the process, machine and tool required. Based on these options, the actual process plan is generated.

Fig. 8.17 GUI screen of File Generation Module
8.4.4 Process Editing Module

This software has an editing module to facilitate the user to have the machine and tool of his choice in the process plan. This module can be selected interactively from the menu. This module exhibits a form, which gives the feature name, and the process generated for the manufacture of that feature. Based on the process, the user can interactively select the machine and tool. This selection will be included in the process plan. The screen for this module is shown in Fig 8.18.

Initially all the available features in the component are segregated, and then they are classified based on the predefined logic. In the input module all information regarding the part, like the raw material details, blank details and job details are keyed in. After the part information is entered, the control gets transferred to the feature information. Features are keyed in one by one and their corresponding information like dimensions references, form tolerances and surface finish are given as input. Then the output file is generated. This generated file is the input for the process generation module.
8.5 Conclusion

The software has been tested with a number of industrial components and independent feature configurations. The system yielded satisfactory results. The software is able to support most of the features of tested parts. The software can be modified easily to include new feature or constraint, as the programming has been written in a modular fashion.