APPENDIX A - A SAMPLE STEP FILE - FOR THE PLATE WITH A HOLE COMPONENT

The STEP (AP203) file of the plate with a hole component has been taken in this appendix [124]. The hole is a cylindrical/rotational feature which has been considered in the work. The STEP file is a human-readable text file as shown below. The Plate dimensions are L100mm X W80mm X H20mm, Centrally located through Hole with Radius 10mm.

ISO-10303-21;
HEADER;
FILE_DESCRIPTION(('CATIA V5 STEP Exchange'),'2;1');
FILE_NAME('C:\Documents and Settings\arun\Desktop\components - final\Plate with hole.stp','2010-11-12T04:34:58+00:00','none','none','CATIA Version 5 Release 16 (IN-10)','CATIA V5 STEP AP203','none');
FILE_SCHEMA(('CONFIG_CONTROL_DESIGN'));
ENDSEC;
/* file written by CATIA V5R16 */
DATA;
#5=PRODUCT('Plate with hole','','',[#2]) ;
#1=APPLICATION_CONTEXT('configuration controlled 3D design of mechanical parts and assemblies') ;
#14=PRODUCT_DEFINITION(' ',' ',#6,#3) ;
#16=SECURITY_CLASSIFICATION(' ',' ',#15) ;
#15=SECURITY_CLASSIFICATION_LEVEL('unclassified')
#47=CARTESIAN_POINT(' ','(0.,0.,0.)')
#52=CARTESIAN_POINT('Axis2P3D Location',(50.,40.,19.9))
#57=CARTESIAN_POINT('Axis2P3D Location',(50.,40.,20.))
#61=CARTESIAN_POINT('Vertex',(58.7758256189,35.205744614,20.))
#63=CARTESIAN_POINT('Vertex',(41.2241743811,44.794255386,20.))
#66=CARTESIAN_POINT('Line Origine',(41.2241743811,44.794255386,0.))
#70=CARTESIAN_POINT('Vertex',(41.2241743811,44.794255386,0.))
#73=CARTESIAN_POINT('Axis2P3D Location',(50.,40.,0.))
#77=CARTESIAN_POINT('Vertex',(58.7758256189,35.205744614,3.5527136788E-015))
#80=CARTESIAN_POINT('Line Origine',(58.7758256189,35.205744614,0.))
#92=CARTESIAN_POINT('Axis2P3D Location',(50.,40.,20.))
#97=CARTESIAN_POINT('Axis2P3D Location',(50.,40.,0.))
#109=CARTESIAN_POINT('Axis2P3D Location',(0.,0.,0.))
#114=CARTESIAN_POINT('Line Origine',(0.,40.,0.))
#118=CARTESIAN_POINT('Vertex',(0.,80.,0.))
#120=CARTESIAN_POINT('Vertex',(0.,0.,0.))
#123=CARTESIAN_POINT('Line Origine',(50.,80.,0.))
#127=CARTESIAN_POINT('Vertex',(100.,80.,0.))
#130=CARTESIAN_POINT('Line Origine',(100.,40.,0.))
#134=CARTESIAN_POINT('Vertex',(100.,0.,0.)) ;
#137=CARTESIAN_POINT('Line Origin',(50.,0.,0.)) ;
#153=CARTESIAN_POINT('Axis2P3D Location',(0.,0.,20.)) ;
#158=CARTESIAN_POINT('Line Origin',(50.,0.,20.)) ;
#162=CARTESIAN_POINT('Vertex',(0.,0.,20.)) ;
#164=CARTESIAN_POINT('Vertex',(100.,0.,20.)) ;
#167=CARTESIAN_POINT('Line Origin',(100.,40.,20.)) ;
#171=CARTESIAN_POINT('Vertex',(100.,80.,20.)) ;
#174=CARTESIAN_POINT('Line Origin',(50.,80.,20.)) ;
#178=CARTESIAN_POINT('Vertex',(0.,80.,20.)) ;
#181=CARTESIAN_POINT('Line Origin',(0.,40.,20.)) ;
#197=CARTESIAN_POINT('Axis2P3D Location',(0.,80.,0.)) ;
#202=CARTESIAN_POINT('Line Origin',(0.,80.,10.)) ;
#207=CARTESIAN_POINT('Line Origin',(0.,10.,10.)) ;
#219=CARTESIAN_POINT('Axis2P3D Location',(100.,80.,0.)) ;
#224=CARTESIAN_POINT('Line Origin',(100.,80.,10.)) ;
#236=CARTESIAN_POINT('Axis2P3D Location',(100.,0.,0.)) ;
#241=CARTESIAN_POINT('Line Origin',(100.,0.,10.)) ;
#253=CARTESIAN_POINT('Axis2P3D Location',(0.,0.,0.)) ;
#268=CARTESIAN_POINT('Line Origin',(50.,0.,0.)) ;
#272=CARTESIAN_POINT('Limit',(0.,0.,0.)) ;
#273=CARTESIAN_POINT('Limit',(100.,0.,0.)) ;
#276=CARTESIAN_POINT('Line Origin',(100.,40.,0.)) ;
#280=CARTESIAN_POINT('Limit',(100.,0.,0.)) ;
#281=CARTESIAN_POINT('Limit',(100.,80.,0.)) ;
#284=CARTESIAN_POINT('Line Origine',(50.,80.,0.))  
#288=CARTESIAN_POINT('Limit',(100.,80.,0.))  
#289=CARTESIAN_POINT('Limit',(0.,80.,0.))  
#292=CARTESIAN_POINT('Line Origine',(0.,40.,0.))  
#296=CARTESIAN_POINT('Limit',(0.,80.,0.))  
#297=CARTESIAN_POINT('Limit',(0.,0.,0.))  
#53=DIRECTION('Axis2P3D Direction',(0.,0.,-1.))  
#54=DIRECTION('Axis2P3D Direction',(0.,0.,-1.))  
#58=DIRECTION('Axis2P3D Direction',(0.,0.,-1.))  
#67=DIRECTION('Axis2P3D XDirection',(0.87758256189,-0.479425538604,0.))  
#74=DIRECTION('Axis2P3D Direction',(0.,0.,-1.))  
#81=DIRECTION('Axis2P3D XDirection',(0.,0.,-1.))  
#93=DIRECTION('Axis2P3D Direction',(0.,0.,-1.))  
#98=DIRECTION('Axis2P3D XDirection',(0.,0.,-1.))  
#110=DIRECTION('Axis2P3D Direction',(0.,0.,1.))  
#111=DIRECTION('Axis2P3D XDirection',(1.,0.,0.))  
#115=DIRECTION('Vector Direction',(-1.,0.,0.))  
#124=DIRECTION('Vector Direction',(-1.,0.,0.))  
#131=DIRECTION('Vector Direction',(-1.,0.,0.))  
#138=DIRECTION('Vector Direction',(-1.,0.,0.))  
#154=DIRECTION('Axis2P3D XDirection',(1.,0.,0.))  
#155=DIRECTION('Axis2P3D XDirection',(1.,0.,0.))  
#159=DIRECTION('Vector Direction',(-1.,0.,0.))  
#168=DIRECTION('Vector Direction',(-1.,0.,0.))  

#175=DIRECTION('Vector Direction',(-1.,0.,0.)) ;
#182=DIRECTION('Vector Direction',(0.,-1.,0.)) ;
#198=DIRECTION('Axis2P3D Direction',(-1.,0.,0.)) ;
#199=DIRECTION('Axis2P3D XDirection',(0.,-1.,0.)) ;
#203=DIRECTION('Vector Direction',(0.,0.,1.)) ;
#208=DIRECTION('Vector Direction',(0.,0.,1.)) ;
#220=DIRECTION('Axis2P3D Direction',(0.,1.,0.)) ;
#221=DIRECTION('Axis2P3D XDirection',(-1.,0.,0.)) ;
#225=DIRECTION('Vector Direction',(0.,0.,1.)) ;
#237=DIRECTION('Axis2P3D Direction',(1.,0.,0.)) ;
#238=DIRECTION('Axis2P3D XDirection',(0.,1.,0.)) ;
#242=DIRECTION('Vector Direction',(0.,0.,1.)) ;
#254=DIRECTION('Axis2P3D Direction',(0.,-1.,0.)) ;
#255=DIRECTION('Axis2P3D XDirection',(1.,0.,0.)) ;
#269=DIRECTION('Vector Direction',(1.,0.,0.)) ;
#277=DIRECTION('Vector Direction',(0.,1.,0.)) ;
#285=DIRECTION('Vector Direction',(-1.,0.,0.)) ;
#293=DIRECTION('Vector Direction',(0.,-1.,0.)) ;
#48=AXIS2_PLACEMENT_3D(' ',#47,$,$) ;
#55=AXIS2_PLACEMENT_3D('Cylinder Axis2P3D',#52,#53,#54) ;
#59=AXIS2_PLACEMENT_3D('Circle Axis2P3D',#57,#58,$) ;
#75=AXIS2_PLACEMENT_3D('Circle Axis2P3D',#73,#74,$) ;
#94=AXIS2_PLACEMENT_3D('Circle Axis2P3D',#92,#93,$) ;
#99=AXIS2_PLACEMENT_3D('Circle Axis2P3D',#97,#98,$) ;
#112=AXIS2_PLACEMENT_3D('Plane Axis2P3D',#109,#110,#111) ;
#156=AXIS2_PLACEMENT_3D('Plane Axis2P3D',#153,#154,#155) ;
#200=AXIS2_PLACEMENT_3D('Plane Axis2P3D',#197,#198,#199) ;
#222=AXIS2_PLACEMENT_3D('Plane Axis2P3D',#219,#220,#221) ;
#239=AXIS2_PLACEMENT_3D('Plane Axis2P3D',#236,#237,#238) ;
#256=AXIS2_PLACEMENT_3D('Plane Axis2P3D',#253,#254,#255) ;
#40=PRODUCT_DEFINITION_SHAPE(' ',' ',#14) ;
#300=COMPOSITE_CURVE('Sketch.1',(#275,#283,#291,#299),.U.) ;
#275=COMPOSITE_CURVE_SEGMENT(.CONTINUOUS.,.T.,#274) ;
#283=COMPOSITE_CURVE_SEGMENT(.CONTINUOUS.,.T.,#282) ;
#291=COMPOSITE_CURVE_SEGMENT(.CONTINUOUS.,.T.,#290) ;
#299=COMPOSITE_CURVE_SEGMENT(.DISCONTINUOUS.,.T.,#298) ;
#31=APPROVAL_PERSON_ORGANIZATION(#25,#21,#19) ;
#25=PERSON_AND_ORGANIZATION(#22,#23) ;
#22=PERSON(' ',' ','',$,$,$) ;
#23=ORGANIZATION(' ',' ',' ') ;
#21=APPROVAL(#20,' ') ;
#20=APPROVAL_STATUS('not_yet_approved') ;
#19=APPROVAL_ROLE('APPROVER') ;
#13=DATE_AND_TIME(#11,#12) ;
#12=LOCAL_TIME(10,4,57.,#10) ;
#10=COORDINATED_UNIVERSAL_TIME_OFFSET(0,0,.AHEAD.) ;
#86=ORIENTED_EDGE('',*,*,#65,.T.) ;
#87=ORIENTED_EDGE('',*,*,#72,.F.) ;
#88=ORIENTED_EDGE('',*,*,#79,.T.) ;
#89=ORIENTED_EDGE('',*,*,#84,.T.) ;
#103=ORIENTED_EDGE('',*,*,#96,.T.);
#104=ORIENTED_EDGE('',*,*,#84,.F.);
#105=ORIENTED_EDGE('',*,*,#101,.T.);
#106=ORIENTED_EDGE('',*,*,#72,.T.);
#143=ORIENTED_EDGE('',*,*,#122,.F.);
#144=ORIENTED_EDGE('',*,*,#129,.F.);
#145=ORIENTED_EDGE('',*,*,#136,.F.);
#146=ORIENTED_EDGE('',*,*,#141,.F.);
#149=ORIENTED_EDGE('',*,*,#101,.F.);
#150=ORIENTED_EDGE('',*,*,#79,.F.);
#187=ORIENTED_EDGE('',*,*,#166,.T.);
#188=ORIENTED_EDGE('',*,*,#173,.T.);
#189=ORIENTED_EDGE('',*,*,#180,.T.);
#190=ORIENTED_EDGE('',*,*,#185,.T.);
#193=ORIENTED_EDGE('',*,*,#96,.F.);
#194=ORIENTED_EDGE('',*,*,#65,.F.);
#213=ORIENTED_EDGE('',*,*,#206,.F.);
#214=ORIENTED_EDGE('',*,*,#122,.T.);
#215=ORIENTED_EDGE('',*,*,#211,.T.);
#216=ORIENTED_EDGE('',*,*,#185,.F.);
#230=ORIENTED_EDGE('',*,*,#228,.F.);
#231=ORIENTED_EDGE('',*,*,#129,.T.);
#232=ORIENTED_EDGE('',*,*,#206,.T.);
#233=ORIENTED_EDGE('',*,*,#180,.F.);
#247=ORIENTED_EDGE('',*,*,#245,.F.);
#248=ORIENTED_EDGE('',*,*,#136,.T.) ;
#249=ORIENTED_EDGE('',*,*,#228,.T.) ;
#250=ORIENTED_EDGE('',*,*,#173,.F.) ;
#259=ORIENTED_EDGE('',*,*,#211,.F.) ;
#260=ORIENTED_EDGE('',*,*,#141,.T.) ;
#261=ORIENTED_EDGE('',*,*,#245,.T.) ;
#262=ORIENTED_EDGE('',*,*,#166,.F.) ;
#151=FACE_BOUND('',#148,.T.) ;
#195=FACE_BOUND('',#192,.T.) ;
#51=CLOSED_SHELL('Closed Shell',(#91,#108,#152,#196,#218,#235,#252,#264)) ;
#68=VECTOR('Line Direction',#67,1.) ;
#82=VECTOR('Line Direction',#81,1.) ;
#116=VECTOR('Line Direction',#115,1.) ;
#125=VECTOR('Line Direction',#124,1.) ;
#132=VECTOR('Line Direction',#131,1.) ;
#139=VECTOR('Line Direction',#138,1.) ;
#160=VECTOR('Line Direction',#159,1.) ;
#169=VECTOR('Line Direction',#168,1.) ;
#176=VECTOR('Line Direction',#175,1.) ;
#183=VECTOR('Line Direction',#182,1.) ;
#204=VECTOR('Line Direction',#203,1.) ;
#209=VECTOR('Line Direction',#208,1.) ;
#226=VECTOR('Line Direction',#225,1.) ;
#243=VECTOR('Line Direction',#242,1.) ;
#270=VECTOR('Line Direction',#269,1.)
#278=VECTOR('Line Direction',#277,1.)
#286=VECTOR('Line Direction',#285,1.)
#294=VECTOR('Line Direction',#293,1.)
#266=ADVANCED_BREP_SHAPE_REPRESENTATION('NONE',(#265),#46)
#49=SHAPE_REPRESENTATION(' ',(#48),#46)
#91=ADVANCED_FACE('',(#90),#56,.F.)
#108=ADVANCED_FACE('',(#107),#56,.F.)
#152=ADVANCED_FACE('',(#147,#151),#113,.F.)
#196=ADVANCED_FACE('',(#191,#195),#157,.T.)
#218=ADVANCED_FACE('',(#217),#201,.T.)
#235=ADVANCED_FACE('',(#234),#223,.T.)
#252=ADVANCED_FACE('',(#251),#240,.T.)
#264=ADVANCED_FACE('',(#263),#257,.T.)
#4=APPLICATION_PROTOCOL_DEFINITION('international standard','config_control_design',1994,#1)
#32=APPROVAL_DATE_TIME(#13,#21)
#265=MANIFOLD_SOLID_BREP('Plate with hole in Z dirn',#51)
#11=CALENDAR_DATE(2010,12,11)
#30=CC_DESIGN_APPROVAL(#21,(#16,#6,#14))
#18=CC_DESIGN_DATE_AND_TIME_ASSIGNMENT(#13,#17,(#16))
#29=CC_DESIGN_DATE_AND_TIME_ASSIGNMENT(#13,#28,(#14))
#17=DATE_TIME_ROLE('classification_date')
#28=DATE_TIME_ROLE('creation_date')
#27=CC_DESIGN_PERSON_AND_ORGANIZATION_ASSIGNMENT(#25, #26,(#16)) ;
#33=CC_DESIGN_PERSON_AND_ORGANIZATION_ASSIGNMENT(#25, #34,(#6)) ;
#35=CC_DESIGN_PERSON_AND_ORGANIZATION_ASSIGNMENT(#25, #36,(#6,#14)) ;
#37=CC_DESIGN_PERSON_AND_ORGANIZATION_ASSIGNMENT(#25, #38,(#5)) ;
#26=PERSON_AND_ORGANIZATION_ROLE('classification_officer') ;
#34=PERSON_AND_ORGANIZATION_ROLE('design_supplier') ;
#36=PERSON_AND_ORGANIZATION_ROLE('creator') ;
#38=PERSON_AND_ORGANIZATION_ROLE('design_owner') ;
#39=CC_DESIGN_SECURITY_CLASSIFICATION(#16,(#6)) ;
#60=CIRCLE('generated circle',#59,10.) ;
#76=CIRCLE('generated circle',#75,10.) ;
#95=CIRCLE('generated circle',#94,10.) ;
#100=CIRCLE('generated circle',#99,10.) ;
#267=SHAPE_REPRESENTATION_RELATIONSHIP(' ', ' ',#49,#266) ;
#303=SHAPE_REPRESENTATION_RELATIONSHIP(' ', ' ',#49,#301) ;
#56=CYLINDRICAL_SURFACE('generated cylinder',#55,10.) ;
#3=DESIGN_CONTEXT(' ',#1,'design') ;
#65=EDGE_CURVE('',#62,#64,#60,.F.) ;
#72=EDGE_CURVE('',#71,#64,#69,.F.) ;
#79=EDGE_CURVE('',#71,#78,#76,.T.) ;
#84=EDGE_CURVE('',#78,#62,#83,.F.) ;
#96=EDGE_CURVE('',#64,#62,#95,.F.) ;
#101=EDGE_CURVE('',#78,#71,#100,.T.) ;
#122=EDGE_CURVE('',#119,#121,#117,.T.) ;
#129=EDGE_CURVE('',#128,#119,#126,.T.) ;
#136=EDGE_CURVE('',#135,#128,#133,.T.) ;
#141=EDGE_CURVE('',#121,#135,#140,.T.) ;
#166=EDGE_CURVE('',#163,#165,#161,.T.) ;
#173=EDGE_CURVE('',#165,#172,#170,.T.) ;
#180=EDGE_CURVE('',#172,#179,#177,.T.) ;
#185=EDGE_CURVE('',#179,#163,#184,.T.) ;
#206=EDGE_CURVE('',#119,#179,#205,.T.) ;
#211=EDGE_CURVE('',#121,#163,#210,.T.) ;
#228=EDGE_CURVE('',#128,#172,#227,.T.) ;
#245=EDGE_CURVE('',#135,#165,#244,.T.) ;
#85=EDGE_LOOP('',(#86,#87,#88,#89)) ;
#102=EDGE_LOOP('',(#103,#104,#105,#106)) ;
#142=EDGE_LOOP('',(#143,#144,#145,#146)) ;
#148=EDGE_LOOP('',(#149,#150)) ;
#186=EDGE_LOOP('',(#187,#188,#189,#190)) ;
#192=EDGE_LOOP('',(#193,#194)) ;
#212=EDGE_LOOP('',(#213,#214,#215,#216)) ;
#229=EDGE_LOOP('',(#230,#231,#232,#233)) ;
#246=EDGE_LOOP('',(#247,#248,#249,#250)) ;
#258=EDGE_LOOP('',(#259,#260,#261,#262)) ;
#90=FACE_OUTER_BOUND('',#85,.T.) ;
APPENDIX B - COMPARISONS BETWEEN RESEARCH APPLICATION DEVELOPED AND OTHER COMMERCIAL SOFTWARE'S

The research application developed in the present research work has been compared with other commercially available software's like Mastercam etc.

A component - Plate with a rectangular pocket (prismatic feature) has been taken as input for the research application as well as the commercial software [125]. Then a step by step comparison has been carried out, ending with the generation of CNC part program. The important comparison factors have been brought out and tabulated as shown in Table A.1.

<table>
<thead>
<tr>
<th>SL NO</th>
<th>IMPORTANT FACTORS</th>
<th>RESEARCH APPLICATION DEVELOPED</th>
<th>OTHER SOFTWARES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Importing STEP file of CAD model into the system</td>
<td>Direct import to system and no cleanup/modification s required</td>
<td>The CAD model generated may require cleanup/modifications</td>
</tr>
<tr>
<td>2</td>
<td>Process capabilities have been considered to automate the process planning</td>
<td>The process capabilities have been integrated in the design logic of the system</td>
<td>Process capabilities have not been considered</td>
</tr>
<tr>
<td>3</td>
<td>Tool path selection for machining</td>
<td>Automatic identification &amp; toolpath selection by ISMI module</td>
<td>User input required for toolpath selection</td>
</tr>
<tr>
<td>4</td>
<td>Machine/ Tool selection from realistic library</td>
<td>The system has a DB of machines &amp; tools available only on the shop floor thereby providing a realistic</td>
<td>The system displays a DB of all the machines &amp; tools available worldwide</td>
</tr>
<tr>
<td></td>
<td>Description</td>
<td>Research application</td>
<td>Commercial software's</td>
</tr>
<tr>
<td>---</td>
<td>------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td>5</td>
<td>Integrated platform for all feature types</td>
<td>The system accommodates all feature types in its GUI &amp; logic</td>
<td>Separate system for separate feature type</td>
</tr>
<tr>
<td>6</td>
<td>Automatic Sequencing of machining operations</td>
<td>This feature is a part of the system logic</td>
<td>Sequencing has to be done by user</td>
</tr>
<tr>
<td>7</td>
<td>Intelligent system to facilitate the user to enter the correct data for feed, speed range etc</td>
<td>Design logic compares the values entered with DB values available for processes, suggests &amp; validates them</td>
<td>The values are taken from material/ tool selected &amp; ranges are not available</td>
</tr>
<tr>
<td>8</td>
<td>Sales/ Marketing data is captured &amp; displayed in the form of a Cost estimate &amp; Customer details</td>
<td>A cost estimate along with customer DB is part of the system. Also enable user to store data in pdf format</td>
<td>No such feature available</td>
</tr>
<tr>
<td>9</td>
<td>Scheduling is an integrated module</td>
<td>Scheduling module helps in proper capacity utilization</td>
<td>No such module available</td>
</tr>
<tr>
<td>10</td>
<td>The geometric and technological data is captured by the system for use in PLM</td>
<td>The STEP+ file generated by the system captures Geometric &amp; Technological data</td>
<td>No tool available to capture both the forms of data</td>
</tr>
</tbody>
</table>

Table A.1 Comparison between the Research application and Commercial software's

The following paragraphs have been laid out as per the tabulation done. The comparisons have been explained in the form of screenshots in the ensuing pages and the important parameters have been encircled and highlighted.

- **Importing STEP file of CAD model**

  The STEP file of the solid CAD model when input to the other commercial software's requires some clean up/ modifications before
generation of toolpath. Ex: the rectangular pocket is seen in 2D (portion (b) of Fig A.1) with some edges removed for toolpath selection. Whereas in case of the research application the STEP file can be input and used directly by ISMI for process planning (portion (a) of Fig A.1).

![Plate with a rectangular pocket](image)

Fig A.1 Importing CAD model into the system

- **Defining Origin and stock size**

  The origin and stock size has to be defined or specified in commercial software's by the user (portion (b) of Fig A.2). Whereas in the research application the origin & stock size are calculated as per the input STEP file using the ISMI feature logic (portion (a) of Fig A.2).
• **Process capabilities considered in process planning**

In the commercial software's the process capabilities are not considered for process planning. The toolpath selection, parameter definition has to be done by the user (portion (b) of Fig A.3). Whereas the process capabilities have been integrated in the design logic of the research application and the user need to just specify the values, leads to automatic process generation (portion (a) of Fig A.3).
• **Machine/ Tool library data**

The commercial software's provides a vast library of all the machines and tools available without taking into consideration their availability on the shop floor (portion (b) of Fig A.4). Whereas the research application provides a realistic DB of machines & tools available on the shop floor (portion (a) of Fig A.4).

![Machine/ Tool library](image)

**Fig A.4 Machine/ Tool library**

• **Specifying Feature Parameters**

The important parameters like DOC have to be specified in the commercial software's for process planning and metal cutting (portion (b) of Fig A.5). Whereas such critical parameters are automatically calculated by ISMI in the research application (portion (a) of Fig A.5).
• **Sequencing of Processes**

In the commercial software's the processes need to be selected and then sequenced manually by the user for machining (portion (b) of Fig A.6). Whereas the system logic in the research application automatically sequences the processes based on process capabilities and other criteria (portion (a) of Fig A.6).
• **Intelligent Feed/ Speed user display**

The commercial software's do not provide ranges for speed/ feed etc to the user for validated data entry, these values being calculated from tool or material (portion (a) of Fig A.7). Whereas, in the research application the ranges are shown to the user for proper data entry from a DB of process, material, tools, speed, feed, DOC ranges etc maintained by the product expert (portion (b) of Fig A.7).

![Fig A.7 Feed/Speed User display](image)

• **Platform for various feature types**

The research application provides an integrated GUI that accommodates the logic to identify and process all feature types. Whereas in other software’s separate modules exist depending on
processes like milling, lathe etc. and also based on prismatic/
cylindrical/ surface features.

- **Cost estimate**

A cost estimate giving all the cost related details of a product is an output of the research application. Other commercial software’s do not have such modules inbuilt in them; hence use various other methods to get a cost estimate. For more details refer Chapter 6 on Research contributions.

- **Scheduling**

Scheduling of operations is an integrated module in the research application. In other commercial software’s separate software/ method used to perform the task. For more details refer Chapter 6 on Research contributions.

- **Availability of both geometric and technological data**

This file which is an output of the research application provides the geometrical and technological data for the entire PLM applications. Other commercial software's do not have such an output for PLM support. For more details refer Chapter 6 on Research contributions.
APPENDIX C - MACHINING PROCESSES AND PARAMETERS

- **Machining Time Calculations for processes**

  The formulae utilized to calculate machining time for various machining operations have been discussed in this section [120, 121].

  ➢ **Turning**

  Machining time for turning operation has been calculated using the parameters and equations discussed in this section. An example has been taken to arrive at the machining time equation for $T_c$.

  A steel rod has to be reduced in diameter from $D_1$ to $D_2$ over a length $L$ by straight turning in a centre lathe as indicated in Fig A.8.

  ![Fig A.8 Estimation of machining time in turning](image)

Here, $T_c = \left( \frac{L_c}{N s_o} \right) \times n_p$ ...\(A.1\)

Where $L_c = \text{actual length of cut} = L + A + O$ ...\(A.2\)

$A, O = \text{approach and over run}$

$N = \text{spindle speed in rpm}$

$s_o = \text{feed (tool) in mm/rev}$

$n_p = \text{number of passes required}$
Speed $N$ is determined from cutting velocity $V_c$

$$V_c = \frac{\pi DN}{1000} \text{ m/min} \quad \text{...(A.3)}$$

Where $D =$ diameter of the workpiece before cut

Therefore $N = \frac{1000V_c}{\pi D} \quad \text{...(A.4)}$

The number of passes $n_p$ is mathematically determined from

$$n_p = \frac{D_1 - D_2}{2t} \quad \text{...(A.5)}$$

where, $t =$ depth of cut in one pass, mm.

Thus $T_c$ indicates the equation for Machining time in case of multiple passes.

$$T_c = \frac{\pi DL_c(D_1-D_2)}{2000V_c s_o t} \quad \text{...(A.6)}$$

**Facing**

Machining time for turning operation has been calculated using the parameters and equations discussed in this section. An example (Fig A.9) has been taken to arrive at the machining time equation of $T_c$.

Here $T_c = \frac{R}{(N \times s_o) \times n_p} \quad \text{...(A.7)}$

where $n_p =$ Initial Length - Final Length / $t$

$t =$ depth of cut in one pass in mm and

$R =$ radius of work

![Fig A.9 Estimation of machining time in facing](image-url)
Drilling

Machining time for drilling operation has been calculated using the parameters and equations discussed in this section. An example (Fig A.10) has been taken to arrive at the machining time equation.

\[ T_c = \frac{L_c}{N s_o} \]  \hspace{1cm} \text{...(A.8)}

Where

- \( L_c \) = actual length of cut = \( L_w + A + O + C \) \hspace{1cm} \text{...(A.9)}
- \( L_w \) = Height of workpiece
- \( A, O \) = approach and over run
- \( C = \frac{D}{2} \times \cot \rho \)
- \( D \) = diameter of the hole, i.e drill
- \( \rho \) = half of the drill point angle
- \( N \) = spindle speed in rpm
- \( s_o \) = feed in mm/rev

Speed \( N \) and feed \( s_o \) are selected/determined in the same as in case of turning. Therefore, the drilling time can be determined from
Milling

Machining time for milling operation has been calculated using the parameters and equations discussed in this section. An example (Fig A.11) of plain milling has been taken to arrive at the machining time equation.

\[ T_c = \pi D (L_w + A + O + C) / 1000 V_c s_o \]  

...(A.10)

The machining time \( T_c \) can be calculated using the following equation.

\[ T_c = L_c / s_m \]  

(for job width < cutter length)  

...(A.11)

Where

\[ L_c = \text{total length of travel of the job} = L_w + A + O + D_c / 2 \]  

...(A.12)

\[ L_w = \text{length of the workpiece} \]

\[ A, O = \text{approach and over run} \]

\[ D_c = \text{diameter of the cutter in mm} \]

\[ s_m = \text{table feed in mm/min} = s_o Z_c N \]

\[ s_o = \text{feed per tooth in mm/tooth} \]

\[ Z_c = \text{number of teeth of the cutter} \]

\[ N = \text{cutter speed in rpm} \]
Again N is determined from $V_c$ using Eq A.3.

- **Grinding**

  Machining time for grinding operation has been calculated using the parameters and equations discussed in this section (Fig A.12). The machining time $T_c$ has been calculated for cylindrical grinding.

  Here $T_c = \frac{L}{Nn} \quad \ldots(A.13)$

  $L =$ length of workpiece to be ground
  
  $n =$ number of cuts
  
  $N =$ rpm of workpiece
  
  $s =$ feed in mm/rev of workpiece

  ![Fig A.12 Estimation of machining time in grinding](image)

- **Cutting Speed, Feed, DOC data for processes**

  The cutting speed, feed and DOC data for various operations depending on material, size and other factors has been discussed in this section [121, 122]. This data has been fed to the DB for support.
The cutting speed and feed data for turning operations has been depicted in the table A.2. For a given work material and tool material, for a specified DOC and feed range, the cutting speed range can be found from the table [121, 122].

<table>
<thead>
<tr>
<th>Work Material</th>
<th>Tool Material</th>
<th>Cutting Speeds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Depth of cut in mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 - 10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Feeds in mm / rev.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.5 - 0.6</td>
</tr>
<tr>
<td>Free Machining Steels</td>
<td>HSS</td>
<td>20 - 50</td>
</tr>
<tr>
<td></td>
<td>Carbidé</td>
<td>100 - 150</td>
</tr>
<tr>
<td>Mild Steel</td>
<td>HSS</td>
<td>25 - 35</td>
</tr>
<tr>
<td></td>
<td>Carbidé</td>
<td>60 - 120</td>
</tr>
<tr>
<td>Medium Carbon Steel</td>
<td>HSS</td>
<td>15 - 25</td>
</tr>
<tr>
<td></td>
<td>Carbidé</td>
<td>50 - 110</td>
</tr>
<tr>
<td>Alloy Steels</td>
<td>HSS</td>
<td>15 - 20</td>
</tr>
<tr>
<td></td>
<td>Carbidé</td>
<td>30 - 65</td>
</tr>
<tr>
<td>Tool steel</td>
<td>HSS</td>
<td>15 - 20</td>
</tr>
<tr>
<td></td>
<td>Carbidé</td>
<td>50 - 110</td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>HSS</td>
<td>15 - 20</td>
</tr>
<tr>
<td></td>
<td>Carbidé</td>
<td>35 - 60</td>
</tr>
<tr>
<td>Cast Irons Grey, ductile and malleable</td>
<td>HSS</td>
<td>20 - 25</td>
</tr>
<tr>
<td></td>
<td>Carbidé</td>
<td>60 - 90</td>
</tr>
<tr>
<td>Aluminium Alloys</td>
<td>HSS</td>
<td>40 - 75</td>
</tr>
<tr>
<td></td>
<td>Carbidé</td>
<td>60 - 150</td>
</tr>
<tr>
<td>Copper Alloys</td>
<td>HSS</td>
<td>40 - 60</td>
</tr>
<tr>
<td></td>
<td>Carbidé</td>
<td>50 - 110</td>
</tr>
<tr>
<td>Magnesium Alloys</td>
<td>HSS</td>
<td>40 - 75</td>
</tr>
<tr>
<td></td>
<td>Carbidé</td>
<td>60 - 150</td>
</tr>
<tr>
<td>Titanium Alloys</td>
<td>HSS</td>
<td>10 - 15</td>
</tr>
<tr>
<td></td>
<td>Carbidé</td>
<td>15 - 30</td>
</tr>
</tbody>
</table>

Table A.2 Cutting Speed, Feed and DOC data for Turning
Milling operations

The cutting speed and feed data for milling operations has been depicted in the table A.3. For a given work material and tool material, for a specified milling type, the cutting speed range and feed can be found from the table.

<table>
<thead>
<tr>
<th>Work Material</th>
<th>Tool Material</th>
<th>Cutting Speed m/min</th>
<th>Feed mm per tooth</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Face Milling</td>
<td>Slab Milling</td>
</tr>
<tr>
<td>Free Machining Steel</td>
<td>HSS</td>
<td>35 - 40</td>
<td>0.3</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>Carbide</td>
<td>90 - 120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mild Steel</td>
<td>HSS</td>
<td>20 - 40</td>
<td>0.25</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>Carbide</td>
<td>85 - 130</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium Carbon Steel</td>
<td>HSS</td>
<td>15 - 30</td>
<td>0.2</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>Carbide</td>
<td>60 - 100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alloy Steel</td>
<td>HSS</td>
<td>10 - 25</td>
<td>0.15</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Carbide</td>
<td>40 - 60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tool Steel</td>
<td>HSS</td>
<td>10 - 25</td>
<td>0.2</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>Carbide</td>
<td>60 - 85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>HSS</td>
<td>10 - 20</td>
<td>0.15</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Carbide</td>
<td>25 - 60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cast Irons*</td>
<td>HSS</td>
<td>30 - 35</td>
<td>0.35</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>Carbide</td>
<td>65 - 100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alumninium Alloys</td>
<td>HSS</td>
<td>55 - 100</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>Carbide</td>
<td>65 - 180</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper Alloys</td>
<td>HSS</td>
<td>40 - 80</td>
<td>0.3</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>Carbide</td>
<td>60 - 100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magnesium Alloys</td>
<td>HSS</td>
<td>60 - 100</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>Carbide</td>
<td>60 - 180</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Titanium alloys</td>
<td>HSS</td>
<td>10 - 30</td>
<td>0.15</td>
<td>0.125</td>
</tr>
<tr>
<td></td>
<td>Carbide</td>
<td>25 - 50</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Grey, ductile and malleable

Table A.3 Cutting Speed and Feed data for Milling
Drilling and Reaming operations

The cutting speed and feed data for drilling and reaming operations has been depicted in the tables A.4 and A.5. For a given work material, the cutting speed range for drilling and reaming can be found. For a given hole diameter, feed range also can be found out.

<table>
<thead>
<tr>
<th>Work Material</th>
<th>Cutting Speed – m/min</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Drilling</td>
</tr>
<tr>
<td>Free Machining Steels</td>
<td>20 - 30</td>
</tr>
<tr>
<td>Mild Steel</td>
<td>20 - 25</td>
</tr>
<tr>
<td>Medium Carbon Steel</td>
<td>15 - 20</td>
</tr>
<tr>
<td>Alloy Steels</td>
<td>15 - 22</td>
</tr>
<tr>
<td>Tool Steel</td>
<td>5 - 8</td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>10 - 15</td>
</tr>
<tr>
<td>Cast Irons*</td>
<td>20 - 25</td>
</tr>
<tr>
<td>Alluminium Alloys</td>
<td>30 - 55</td>
</tr>
<tr>
<td>Copper Alloys</td>
<td>25 - 45</td>
</tr>
<tr>
<td>Magnesium Alloys</td>
<td>60 - 111</td>
</tr>
<tr>
<td>Titanium alloys</td>
<td>10 - 15</td>
</tr>
</tbody>
</table>

Table A.4 Cutting Speed data for Drilling and Reaming

<table>
<thead>
<tr>
<th>Hole Diameter mm</th>
<th>Feed in mm / rev</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Drilling</td>
</tr>
<tr>
<td>1 - 2</td>
<td>0.04 - 0.06</td>
</tr>
<tr>
<td>2.5 - 4</td>
<td>0.05 - 0.1</td>
</tr>
<tr>
<td>4.5 - 6</td>
<td>0.05 - 0.15</td>
</tr>
<tr>
<td>6.5 - 8.5</td>
<td>0.1 - 0.2</td>
</tr>
<tr>
<td>9 - 12</td>
<td>0.15 - 0.2</td>
</tr>
<tr>
<td>12 - 14</td>
<td>0.15 - 0.25</td>
</tr>
</tbody>
</table>

Table A.5 Feed data for Drilling and Reaming
Grinding operations

The cutting speed and feed data for grinding operations has been depicted in the Fig A.13.

---

**Fig A.13 Cutting speed, Feed and DOC data for Grinding**
• **Manufacturing time calculations**

The Manufacturing time for any process consists of the following components as shown in Fig A.14 [121].

- Setting time
- Machining time
- Auxiliary time
- Delay time

![Diagram of Manufacturing Time Components]

**Fig A.14 Components of manufacturing time**
• **Product cost calculations**

The Product cost has been calculated by considering the following parameters [123]:

- Machining cost (hourly basis)
- Tooling cost
- Labor cost
- Raw material cost (per kg)
- Manufacturing Overheads (%)
- Sales Overheads (%)
- Profit (%)

The method of cost calculation has been discussed below.

1. Machining cost in Rs = (Machining time * Machining cost/ hour) /60 …(A.14)
2. Manufacturing cost = Machining cost + Tooling cost + Labor cost + Raw material cost …(A.15)
3. Manufacturing Overhead cost = Manufacturing Overhead % of (Manufacturing cost) …(A.16)
4. Sales Overhead cost = Sales Overhead % of (Manufacturing Overhead cost + Manufacturing cost) …(A.17)
5. Total cost = Manufacturing cost + Manufacturing Overhead cost + Sales Overhead cost …(A.18)
6. Selling Price/ part = Total cost + (Profit % of (Total cost)) …(A.19)
7. Total Selling Price/ order = Selling Price/ part * Part Quantity …(A.20)
PUBLICATIONS RELATED TO THE RESEARCH WORK


