THE APPLICATION OF FEATURE TECHNOLOGY IN DEVELOPING A CAD-BASED HIGH LEVEL PROCESS PLANNING SYSTEM

Ade Febransyah
Workgroup for Innovation in Decision Making (WIDE)
Prasetiya Mulya Graduate School of Management
e-mail: afebran@pmulya.ac.id

ABSTRACT

High-level process planning plays an important role in determining candidate process domains at the configuration design stage. Changing the process domains later increases the product development cycle and the product development cost. Therefore, determining the most appropriate manufacturing processes at the beginning stages of the design process becomes critical. However, high-level process planning systems have traditionally lacked integration of design synthesis and design evaluation. The objective of this paper is to propose a CAD-based high-level process planning system that will help designers decide whether or not the designs are worth pursuing. A hybrid approach incorporating design by feature and feature recognition approaches is proposed and implemented. Synergizing both advantages of both approaches will reduce the complexity of feature recognition algorithm without sacrificing the flexibility in creating a part model.

Keywords: high level process planning, design by feature, feature recognition, concurrent engineering, process selection.

1. INTRODUCTION

It becomes evident that a large percentage of product costs are determined at the configuration design stage (Ullman, 1992; Miller, 1993). This implies that once the design stage is completed, there is little opportunity to reduce the product cost since a significant portion of its cost is already determined (Singh, 1996). Based on this fact, companies strive to consider economic factors as early as possible in the design process.

However, in practice, the so-called *over the wall approach* is still commonly used, where designers work on product design and then throw the design over the wall to the manufacturing engineers to produce (Boothroyd et al., 1994). The design engineers are only responsible for designs of products that can function properly without considering the manufacturability of their designs. A *back and forth* process usually occurs when the manufacturing engineers find that the designed products cannot be manufactured or are difficult to manufacture and thus they have to send the designs back to the design engineers for revision. This is a lengthy and expensive process that unnecessarily extends the product development cycle.

Lack of manufacturing knowledge among designers is considered the main cause of the current inefficient product development process. An experienced designer repeatedly chooses the manufacturing processes he or she is familiar with, without considering alternative processes and materials. For example, a designer with experience in die-casting tends to choose die-casting again and again for most design problems. In the current manufacturing industry where product designs change very rapidly and products are often made in small batches, this habit-driven mentality could be harmful to the process of innovation (Smith, 1999).

To avoid this problem, many companies have adopted some forms of concurrent engineering. One important element of concurrent engineering is *Design for Manufacture* (DFM). DFM aims to bridge the gap between the design and manufacturing stages. The ultimate goal of DFM is that once a design is completed, it is ready for manufacture. But the DFM analysis typically focuses on a specific manufacturing process domain, i.e. machining, die-casting, injection molding, stamping, etc. It is assumed that certain process candidates have already been designated for a given part design before the DFM analysis can be made. The other fact is that DFM guidelines are employed when the part is in the detailed design stage. One important task preceding design for manufacture analysis is the selection of manufacturing processes at the preliminary stage of design.

2. LITERATURE REVIEW IN HIGH-LEVEL PROCESS PLANNING SYSTEMS

A great deal of research has been performed in the area of process planning. Most of this research is concentrated on the development of manufacturing processes with detailed specifications such as jigs and fixtures, machine tools, tooling, machining parameters, etc. The Computer-Aided Process Planning (CAPP) systems rely on detailed part specifications. The proposed approach in this paper aims to provide an early determination of process and cost estimates while the part is being designed. This is referred to as high-level process planning (HLPP). The output of HLPP may influence the detailed design specifications. No effort is made here to provide a review of "low-level" process planning research. Research on low-level process planning is well documented by Alting and Zhang (1989).

There is a large body of research related to low-level process planning including the development of various CAPP systems for machined parts. However, there has been relatively little work done in the area of high-level process planning. In this chapter, some important research activities that have made major contributions to the development of process and/or material selection systems are presented. Since the research employs feature modeling as the basis for the part description, a separate section is devoted to a review of research related to feature modeling.

Farris (1992) developed an *expert processing sequence selector* that facilitates some appropriate combinations of primary processes and materials. The procedures in this system are divided into four categories: geometry input, process selection, material selection and system update. In describing the geometry of the part, the user classifies it according to size, shape, cross section and features. *Pattern-matching* is used for process-shape relationships and process candidates are selected based on rules that consider the geometry of the part. Primary process selection is made with regard to the restrictions on the size of the enclosing envelope, the size and shape of the fundamental envelope and the cross-section of the part. Each feature on the part is assessed as to whether the primary process can also form the feature. If the primary process cannot make a feature, then the system finds the primary/secondary processes to make the feature. The material selection procedure utilizes fuzzy logic to model the imprecise material constraints and to select appropriate materials. The final step is to provide an early cost estimate for each process and material combination. Process coverage includes injection molding, plastic extrusion, blow molding, thermoforming, foam molding, rotational molding, thermoset compression molding, transfer molding, and compression molding.

Yu (1993) developed the Computer-Aided Design System for Manufacturing Process Selection. Their work focuses on net-shape manufacturing processes such as injection molding, die casting and forging. In determining the process candidates, the system uses an index that is calculated by design compatibility analysis (DCA), which measures the compatibility between the decision factors in process selection and the process candidates. The process candidates are ranked based on the so-called *match index.* This system gives valuable information to designers in terms of ranking the process candidates. Since in this work, the part geometry is described based on shape classification and its envelope size, the process-shape relationship is not as complete as the Expert Process Sequence Selector developed by Farris (1992). Computer-Aided Design for Manufacturing Process Selection does not provide information on early cost estimate.

The Cambridge Materials Selector (CMS) was introduced mainly as a material selection system (Esawi, 1998). This system concentrates on the data modeling aspect by presenting the data in chart format. This data is then used in a process selection system, called the Cambridge Process Selector (CPS). The CPS database contains records of 125 processes and their attributes, which makes this system among the most comprehensive in terms of process coverage. The CPS approach consists of two steps. The first step screens out processes that cannot meet the design requirements. The second step ranks the selected candidates by economic criteria.

COMPASS, developed as a *Meta* planner, is intended to bring manufacturing issues upstream by generating timely and appropriate feedback to design engineers (Chan, 1998). The COMPASS system is perhaps the first work in this area that uses the term *high-level process plan* as an outcome of a Meta planner. In contrast to many existing *low-level* process planning systems that cover *depth*, COMPASS covers *width*. The term depth here refers to the outcome of the low-level process planning system that is very specific, i.e. including tool selection, operation sequence, cutting parameters, etc. On the other hand, the term width refers to the outcome of COMPASS that mainly focuses on selecting feasible process candidates. A high-level process plan in COMPASS contains complete coverage of all feasible processes for the given design. While many CAPP systems focus heavily on machining processes, this system is aimed at covering a wide spectrum of process domains. The COMPASS system is considered more *dynamic* than most others, since it considers the real-time shop floor status in the decision making process. Not only does the system select feasible processes, but it also considers equipment and tools availability at the manufacturing facility. Even though the system lacks implementation details, it provide a fundamental framework of how a complete high-level process planning system can be developed. It is said that the system will receive a CAD file as input and convert it into a standardized format for the system. The authors do not state how a part and the features on the part should be recognized and extracted from a CAD drawing. It is not also clear how design features are mapped to process features.

Giachetti (1998) developed a decision support system for Material and Manufacturing Process Selection, MaMPS. The system is divided into three modules: the material selection module, the process selection module, and the aggregation module. In this system, fuzzy set theory and relational database technology is used in each module for the related decision making procedures. The material selection module and the process selection module are independent from each other. The material selection module evaluates the compatibility between possible candidate materials and the input material requirements. Likewise, the process selection module evaluates the compatibility between the characteristics of the alternative processes and the input design specifications. An aggregation module joins the two aggregated compatibility ratings. The outcome is a final ranking of possible combinations of materials and manufacturing processes. While other systems typically provide either decision support or database support, MaMPS offers a combination of decision-making theory with database management. MaMPS, like the other systems described in this chapter, is not CAD-based. The system uses a rudimentary method of describing part geometry, and it does not provide any estimate of cost. Design synthesis and design evaluation cannot be made simultaneously, which lengthens the design development cycle.

Manufacturing Advisory Service (MAS) was developed by Smith (1999) as a manufacturing process and material selection tool. MAS generates a dialogue with the designer, inquiring about batch size, typical tolerances, size, overall shape, and cost requirements. At each step along the way, the user is presented with an updated, ranked list of manufacturing possibilities. A similar method is used to define the attributes for material selection such as yield strength and density to generate material rankings. The final result is a ranked list of viable combinations of materials and processes, obtained through a process/material pair optimization. MAS has been the most comprehensive high-level process planning system, since it accommodates almost all of the capabilities of the previous systems. Giachetti's work is adopted in ranking all possible combinations of materials and processes. In addition to performing primary process selection, MAS also sequences processes. However, since a part is described based on a geometry-based group classification, the misclassification of part shape is frequently encountered.

There are several textbooks and handbooks that provide guidelines in material and manufacturing process selection. One is "Engineering Design and Design for Manufacturing a Structured Approach: Text and Reference for Mechanical Engineers" from Dixon and Poli (1995) that uses two approaches: the *process first approach* and the *material first approach* in solving the material and process selection problems. In the process-first approach, the input is the part information about production volume, size, and shape. Using the part information, feasible processes are identified. Once a process has been selected, the next step is to find a material class that is associated with the selected process. Application information is then applied to identify the final feasible material class(es). In the material-first approach, the search starts with application information. Feasible material classes are determined based on the application information. From the list of feasible material candidates, associated processes are then selected. After considering part information, the final feasible processes are listed. It is stated that both approaches should end up with the same results.

Most work on process planning systems pertains to low-level process planning. Most of the research in the field of process planning focuses on the low-level process planning, where a detailed process plan is automatically generated. Numerous Computer-Aided Process Planning (CAPP) systems have been developed that deal with a single process domain such as machining or forming. Only a handful of research activities have addressed process planning at the higher level.

In recent years, feature technology has been used in an effort to realize the integration of CAD and CAM. Feature-based modeling is mostly used in low-level process planning systems (Shah and Mäntylä, 1995). These low-level process-planning systems consider only machining processes, and the features included are called machining or process planning features. If the design features represent the geometry construction units, then the machining or process planning features would represent the volume of material that needs to be machined. One of the shortcomings of the designing with machining features is that only negative features, such as holes and slots, are available (Smith and Wright, 1997).

This paper will focus on the implementation of feature technology in high-level process planning, and the concept of *design by features* and *feature recognition* will be adopted. The main focus in the paper is to develop an effective concurrent engineering tool that will help the designers create a part and at the same time perform design evaluation. Since a part is built from predefined features with known or given attributes, once a part is completely created, a database of all design attributes is established. These design attributes are then used for downstream applications such as process selection, cost analysis, and manufacturability.

3. THE FEATURE-BASED DESIGN AND PROCESS PLANNING (FEBDAPP) SYSTEM'S FRAMEWORK

Figure 1 shows the overall framework of the Feature-Based Design and Process Planning (FEBDAPP) system (Febransyah, 2001). As shown in the figure, the existing high-level process planning systems have focused primarily on process selection. Although they are computer-aided systems, most of them call for manual input of design attributes and are not CAD-based. In part creation, designers use either predefined features or a sketch in creating a part. When dealing with the most frequently used parts, the design by features approach will be more favorable, since feature information can be directly derived. However, designers will frequently have to create more complex parts from sketches for which predefined features cannot be used. Even though the design by feature approach tries to eliminate the task of feature recognition, a search algorithm is still needed for certain information that is required for downstream applications.

In this research, a hybrid system of design by feature and feature recognition approaches is employed for the following reasons:

1. Designers tend to model parts from sketches rather than predefined features, unless they are dealing with standardized or frequently used parts. In other words, a *pure* design by feature approach alone is only suitable for standardized parts.
2. Even though a whole part is built from predefined features, the feature recognition approach is still needed for recognizing application-dependent features, such as undercuts in injection molding and die-casting and part shape in process selection.

Once a part is created, a primary representation in terms of design feature is established. When a part is built from all predefined features, such as holes, slots, and bosses, the part is represented at the macroscopic or higher level. If there is at least one feature that is created from a sketch rather than from a predefined feature, then a part is represented in both high and low levels. In the primary representation, a part is the aggregation of features and feature relationships. The information from the primary representation cannot be used for downstream applications. Feature mapping is then required to convert the primary representation into the application-dependent secondary representation. It should be noted that this secondary representation is application-dependent. This means that the secondary representation for cost analysis is different from that for manufacturability; the secondary representation for cost analysis of die-casting is different from that for cost analysis of stamping and so on. However, it is intended that the feature mapping mechanism be generic so that the system can be customized for different applications with minimal effort (Shah and Mary, 1988).

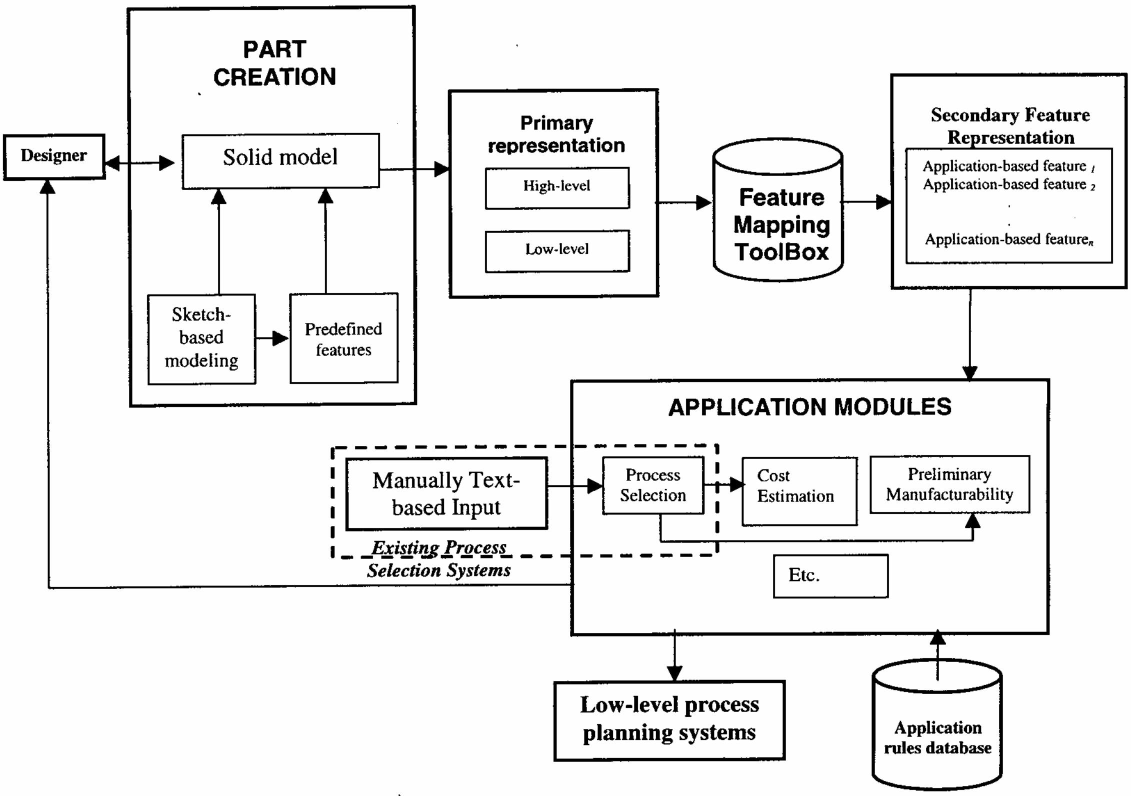


Figure 1. The framework of the Feature-based Design and Process Planning (FEBDAPP) System

In a high-level process planning system, there are decision factors that need to be defined. They can be classified as related to *geometrical features, technological features, and production features* (Giachetti, 1998). Since this paper is intended to select candidate primary processes for a given part, the focus is on geometrical features. The other inputs to the system are imprecise in nature. Due to the impreciseness of technological and production requirements, a fuzzy logic approach is employed in the high level process planning system. The geometrical features covered in this research are (1) part shape, (2) wall thickness, (3) undercuts, (3) parting plane types and (5) part size. These five features are the most important features in determining the primary candidate processes. For the sake of discussion, only part shape definition is presented in this paper

In such an automated system, it is intended that the shape of a part is automatically defined from a CAD model rather than by the user. It should be noted here that part shape definition is required by numerous downstream applications such as process selection and Group Technology for Classification and Coding. One main task of this research has been to develop knowledge for each shape classification and then to store that knowledge in the CAD system so that the system automatically recognizes the shape of the part. In order to do that, the characteristics of each part shape need to be examined.

Using an incremental shape definition procedure, complex shapes can be defined. In feature-based modeling, a part, P is built from a set of design features, F_i

$$P = \{F_1, F_2, \ldots, F_n\}$$

In order for a CAD system to recognize the part shape, rules must be developed. For this purpose, an *incremental shape definition* technique is introduced. The purpose of using this technique is to avoid complex shape definition recognition that requires consideration of the whole part. Using the incremental technique, the part shape definition evolves as each new design feature is added.

Figure 2. illustrates the overall procedures that show the incremental shape definition. The designer starts with a cylindrical block, F_1 as a base feature. This cylinder feature can be created by either extruding a 2-D circle sketch or revolving a 2-D rectangle sketch around an axis of revolution. At this stage, the current shape of design can be defined as either solid axial (revolving process) or constant cross-section (extruding). In Figure 2(b), a smaller cylinder, F_2 is added. These two features are collinear since they both share the same axis of revolution. After this feature is added to the design that happens to be F_1, constant cross-section is removed as a candidate shape. As a result, the current design is either a rotational part or a solid axial part. Now, suppose another smaller cylinder, F_3 is added as seen in Figure 2(c). Since the axis of F_3 does not lie on that of F_1 and F_2, the part can no longer be a solid axial. Instead it becomes a prismatic part.

From the figure, it is shown that

(a) $S_1 = f(S_0, F_1, R_1) = f(S_0)$ for the first feature

(b) $S_2 = f(S_1, F_2, R_2)$

(c) $S_3 = f(S_2, F_3, R_3)$

After adding *n* features,

$S_n = f(S_{n-1}, F_n, R_n)$

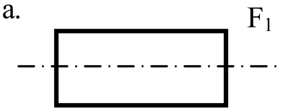
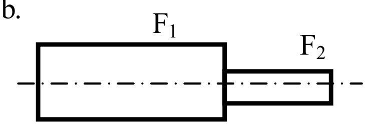
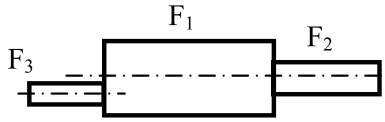
Incremental design process	Position & orientation	Current shape
a. 		*P={F₁}* *S= {solid axial, constant cross section}*
b. 	Collinear	*P={F₁, F₂}* S={solid axial}
c. 	Parallel	*P={F₁,F₂, F₃}* *S={prismatic}*

Figure 2. Incremental Shape Definition Procedure

where,

S_n is the shape after adding n^{th} feature

F_n is the n^{th} feature

R_n is the relationship between feature F_n and the existing design shape S_{n-1}

It should be noted here, that for rotational or solid axial parts, all features should be cylindrical features. For non-rotational parts such as prismatic parts, there must be at least one feature that is not cylindrical. In order to implement the incremental shape definition rules, it is necessary to extract low-level feature information from the CAD system. This information pertains to the feature object themselves as well as the relationships between features. The following is an example of pseudocodes for defining feature objects.

```
START
        For each Feature, Fi
        Get FeatureCreation, FeatC

        IF FeatC  is  Positive-Extrude Then
                Get ParentSketch   ' get a sketch to create the feature
                Get LineSketchCount           ' get the number of lines in a sketch
                Get ArcSketchCount            ' get the number of arcs in a sketch
                If ArcSketchCount=1 And OtherSketchesCount=0 Then
                        ParentSketch is a circle
                        FeatureObject is a cylinder
                ElseIf LineSketchCount=4 Then
                        For each Line
                                Get LineParams   ' get line information
                                Get LineVector   '
                        Next Line
                        Get LineRelations ' get relations between lines
                        If there are two lines parallel to each other AND
                                There are two lines orthogonal to two other two lines Then
                                ParentSketch is a rectangle
                                FeatureObject is a box
                        End If
                Else
                        FeatureObject is other constant-cross section
                End If
        End IF
```

4. SYSTEM IMPLEMENTATION

Figure 3. shows the architecture of the FEBDAPP system. FEBDAPP consists of three sub-systems: (1) CAD, (2) user interface, and (3) applications. SolidWorks, the commercial CAD system, is used as the main feature-based design environment. The advantage of using SolidWorks is that it includes a complete API (Application Programming Interface) with functions or methods that can be called from either Visual Basic or Visual C++. Furthermore, SolidWorks shares the same solid modeling engine (Parasolid) as Unigraphics and several other CAD systems. Together, these CAD systems account for large user and application bases. It is expected that procedures developed in this research will be extendable to the CAD environments used in many research institutions and industrial establishments.

The API functions are essential for developing the application software. One example of API functions in this implementation involves determining the box envelope of the part. Not only do these API functions determine the information about the part geometry, but they can be also used to assign attributes to the part geometry. For instance, with API functions, we can specify the tolerance, surface finish, material specification, and other design requirements. Of course, not all API functions built in SolidWorks can fulfill the requirements of this research. If there is no API function that can be used to obtain the secondary representation, new functions or methods are created.

The user interface has been developed using Visual Basic with OLE (Object Linking and Embedding) automation. OLE is a powerful and flexible technology for sharing data between applications. Both SolidWorks and Microsoft Access are OLE-based applications, so creating a Visual Basic interface between them is relatively straightforward.

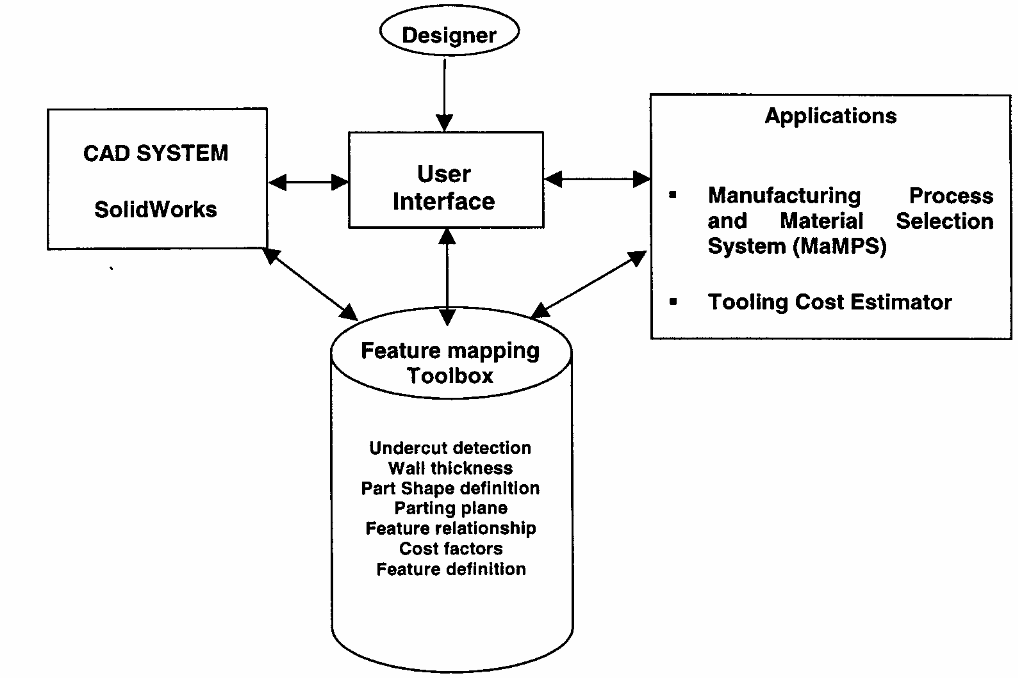


Figure 3. The Architecture of System Implementation

A prismatic part shown in Figure 4. is used for implementation. The FEBDAPP system finds that there is no undercut detected in Z-axis. The minimum and maximum wall thicknesses are obtained to be 4 mm and 5 mm, respectively. As expected, the part shape is defined as a prismatic part. The application-based features to be used for process selection purpose are shown in Figure 5. These features are then transferred to the Giachetti's MaMPS system. After completing the technological and production features as in Figure 6, candidate processes can be determined. The MaMPS system results in machining and die-casting as candidate processes as shown in Figure 7.

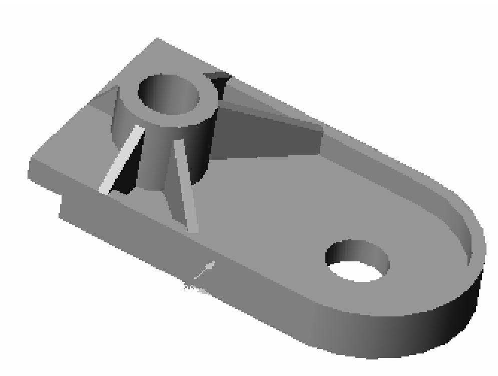


Figure 4. A Prismatic Part

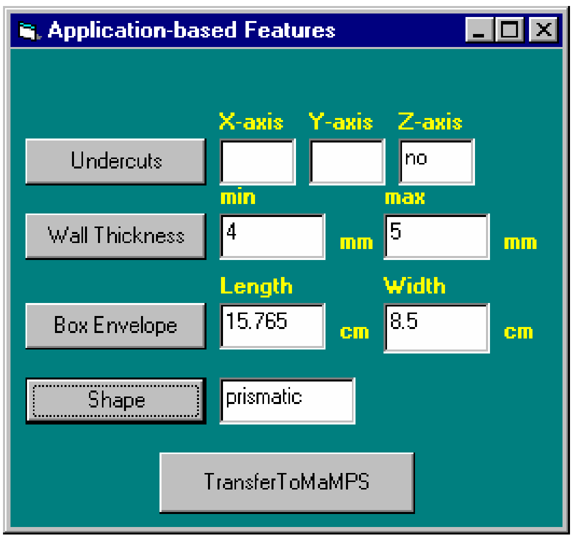


Figure 5. Application-based Features for Process Selection

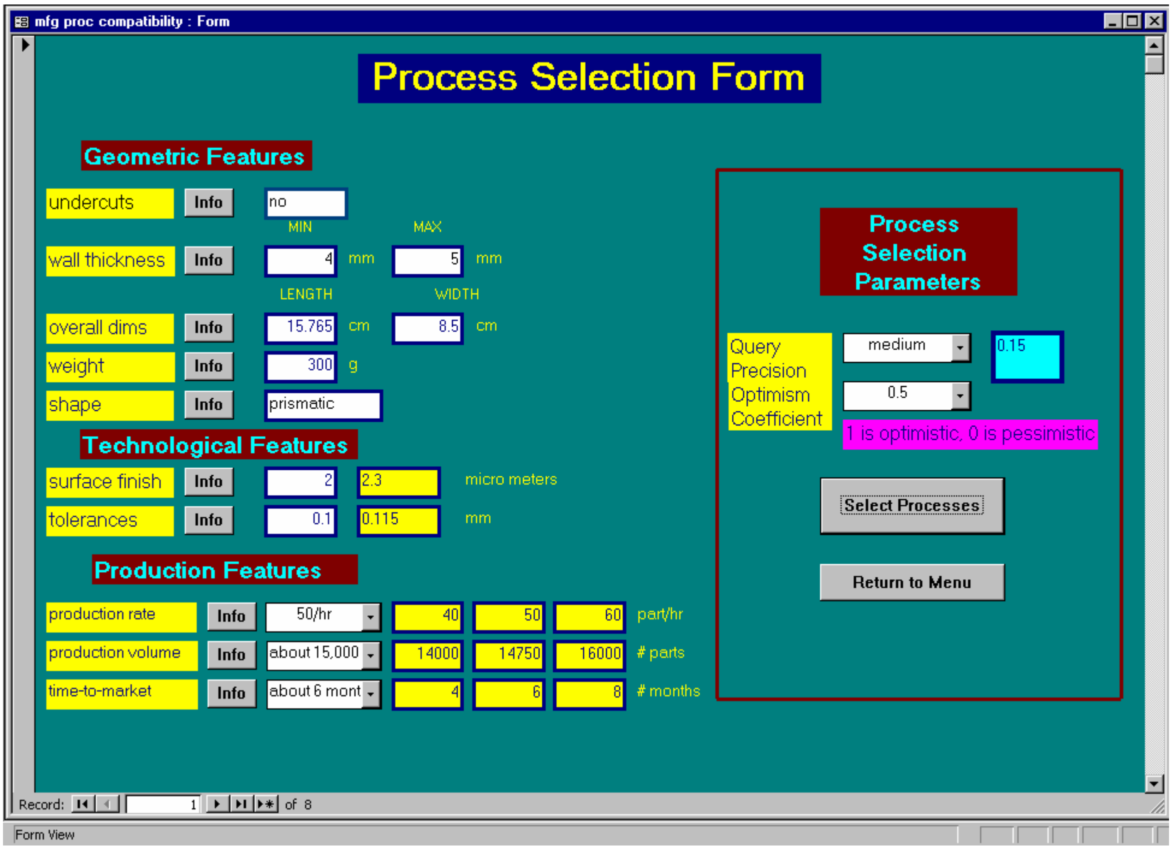


Figure 6. MaMPS' Process Selection Form

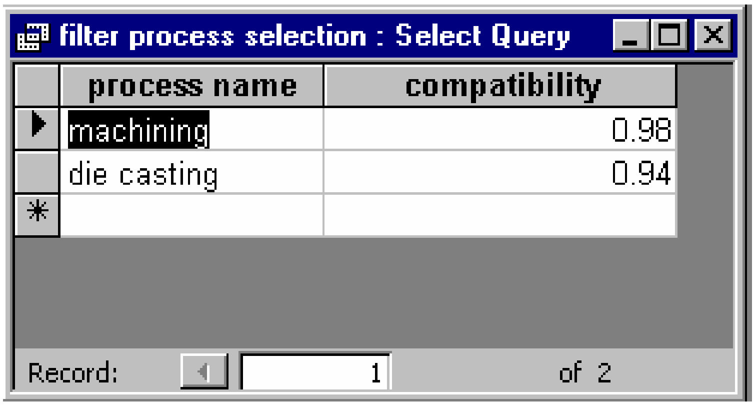


Figure 7. MaMPS Output of Candidate Processes

5. DISCUSSION AND FURTHER RESEARCH

In this paper, a CAD-based high-level process planning system has been developed and implemented. This research is considered the first effort to implement feature technology in integrating an existing CAD system with the advanced manufacturing processes and materials selection systems. It has enabled a simultaneous engineering approach to designs, where designers can obtain on-line manufacturing advisory at the design phase.

This paper takes major steps toward the complete integration of CAD systems and manufacturing applications by developing a hybrid system consisting of design by feature and feature recognition approaches. However, this new approach can be extended to other applications. The following is a list of some further research that can be based on the tools and algorithm developed as part of this research: (1) Enhancing the capability of the system in handling other process domains. Other near net shape manufacturing processes such as powder metallurgy, sand casting, and forging are examples, (2) Developing additional applications and moving closer toward a complete feature-based manufacturing advisory system for conceptual design. The feature mapping approach used in this research can be extended for other applications, such as manufacturability analysis, (3) Developing a neutral feature-based system that is CAD system independent. The Application Programming Interface (API) functions used in this research are SolidWorks functions. When other CAD systems are used as the working design environment, the interface commands may need to be changed, since different CAD developers have their own API functions. In order to avoid this problem, instead of using API, a "neutral" conversion system is required so that the feature-based systems become independent of a particular CAD system, (4) Developing a generic part classification and identification system that covers a wide range of part configurations. The incremental shape definition technique developed in this research works well for defining a part shape, when a part is created in a feature-based working environment. However, the shape classification used in this research is adopted from the existing high-level process planning system. A more generic part classification should be developed in order to cover a wide range of part shapes.

REFERENCES

Alting, L., H. Zhang, 1989. "Computer Aided Process Planning: The State of the Art Survey", *International Journal of Production Research*, vol. 27, no. 4, pp. 535-585.

Boothroyd, G., P. Dewhurst, W., Knight, 1992. "Selection of Materials and Processes for Component Parts", *Proceedings of the 1992 NSF Design and Mfg. Systems Conference*, 1992.

Chan, K., C. King, P. Wright, 1988. "COMPASS: Computer Oriented Materials, Processes and Apparatus Selection Systems", *Journal of Manufacturing Systems,* vol. 17, no. 4, 1988, pp. 275-286.

Chen, Y. M., C.L. Wei, 1997. "Computer-Aided Feature-Based Design for Net Shape Manufacturing", *Computer Integrated Manufacturing Systems*, vol. 10, no. 2, pp. 147-164.

Dixon, J.R., C. Poli, 1995. *Engineering Design and Design for Manufacturing a Structured Approach: Text & Reference for Mechanical Engineers*, Field Stone Publishers, Conway, MA.

Esawi, A.M.K., M.F. Ashby, 1998. "Computer-Based Selection of Manufacturing Processes: Methods, Software and Case Studies", *Journal of Engineering Manufacture*, vol. 212, no. B8, pp. 595-610.

Farris, J., 1992. "Selection of Processing Sequence and Materials During Early Product Design", *Ph.D Thesis,* University of Rhode Island.

Febransyah, A., 2001. ”A Feature-Based Approach to Automating High-Level Process Planning System”, *Ph.D. Dissertation*, North Carolina State University.

Giachetti, R.E., 1998. “A Decision Support System for Material and Manufacturing Process Selection”, *Journal of Manufacturing Systems*, vol. 9, pp. 265-276.

Miller, L.C.G., 1993. *Concurrent Engineering Design: Integrating the Best Practices for Process Improvement*. Society of Manufacturing Department, Dearborn, Michigan.

Shah, J.J., M. Mäntylä, 1995. *Parametric and Feature-Based CAD/CAM Concept, Techniques, and Applications*, John Wiley & Sons, Inc., New York.

Shah, J.J., T.R. Mary, 1988. “Functional Requirement and Conceptual Design of the Feature-Based Modeling System”, *Computer-Aided Engineering Journal*, February, pp. 9-15.

Singh, N., 1996. *Systems Approach to Computer Integrated Design and Manufacturing*. John Wiley & Sons, Inc. New York.

Smith, C.S., 1999. “The Manufacturing Advisory Service: Web Based Process and Material Selection, *Ph.D Dissertation*, University of California, Berkeley.

Ullman, D.G., 1992. *The Mechanical Design Process*, McGraw-Hill, New York.

Yu, J. C., S. Krizan, K. Ishii, 1993. “Computer-Aided Design for Manufacturing Process Selection”, *Journal of Intelligent Manufacturing*, vol. 4, pp. 199-208.