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Computer Aided Design for Manufacturing Process Selection

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This paper describes an expert system that helps designers select a manufacturing process in the early stage of product design. First, the paper focuses on net-shape manufacturing processes and identifies the major factors that affect the selection of an appropriate process. Examples of these factors include shape, production volume, and material. A versatile methodology should consider all the factors simultaneously in assessing the suitability of the candidate processes. The proposed system uses the concept of design compatibility analysis to represent the suitability of candidate processes with respect to the given product specifications. The system uses this knowledge to eliminate incompatible candidates and rank the compatible set of processes. A prototype system called DFPS uses HyperCard and Prolog to implement the proposed methodology. DFPS also contains information related to each process.

Keywords: Concurrent engineering, process selection, expert system, design compatibility analysis, design for manufacture

1. Introduction

1.1 Background

In recent years, concurrent engineering has emerged as a key practice in enhancing the competitiveness of a product. Most people agree that the cost and quality of a product are "locked" into the layout design. Many companies are actively pursuing means to integrate the life-cycle values of the product early in its development. In particular, design for manufacturability (DFM) has provided engineers a systematic methodology to reduce development time, cut production cost, and reduce defects. DFM typically focuses on a particular manufacturing process, e.g., machining, stamping, injection molding, assembly, etc., and seeks to incorporate into the early product design measures that can prevent manufacturing problems and significantly simplify the production process.

While this type of activity certainly enhances product competitiveness it usually applies to a specific process. What precedes DFM is a very important decision, selection of the material and manufacturing process. Frequently encountered process selection targets include (1) electronics housings: sheet metal forming or injection molding, (2) automotive parts: machining, die casting or investment casting. These decisions not only affect the DFM methods that follow, but also the product's overall market competitiveness. A variety of factors influence this decision, many of which cannot be estimated accurately, e.g., volume of sales. While there are many handbooks for qualitative guidance in selecting a process, they do not provide a quantitative means to compare the suitability of each process to a given part. Today, most engineers select a process based on their experience and intuition in addition to "guesstimation" (estimation based on educated guesses) of many of the influencing factors. Engineers can greatly benefit from a design tool that allows them to compare different processes in a more rational, systematic manner, utilizing as much quantitative information as possible.

This paper reports on our research to develop a systematic methodology for process selection. We focus on net-shape processes such as injection molding, die casting, and forging. Also identified in this paper are the factors influencing process selection and indications of the iterative nature of some of the decision variables. This information is currently compiled as HyperCard stacks intended for documentation as well as designer training. Then, we describe an expert system that utilizes qualitative and quantitative information on compatibility of candidate processes to various product specifications. A designer would use this system in the preliminary stages of design to screen through a large set of possible processes and derive a small set of suitable processes.

1.2 Related Work

The past five years have seen a surge of research and development work involving DFM. Perhaps the most notable work was in design for assembly (DFA) pioneered by Boothroyd and Dewhurst (1983). Their work on assembly has an indirect influence in process selection. DFA recommends separate parts to be integrated into one unless there is a compelling reason not to. Integration of parts usually leads to a different process, typically a near net-shape process like die casting or injection molding. Yet, DFA only focuses on assembly cost and does not take into account possible increases in part cost. There are studies of similar nature addressing different processes. Lai and Wilson (1985) assume that the part cost is given. Cutkosky *et al.* (1989), Shah *et al.* (1990), and many others address machining process. Our own work focuses on design for net-shape manufacturing. Ishii, *et al.* (1989b) look at design for injection molding, while Liou and Miller (1991) focus on design for die casting. In Maloney *et al.* (1989), we focused on the compatibility between forging designs and the proposed process and equipment. Each work cited above concentrates on a single process and deals with more or less a detailed design which is suitable for the process in question. Although Ishii and Nekkanti (1989a) pursued a general framework for representing knowledge about design for net-shape manufacturing, their paper still concentrated on injection molding. Work that addresses the comparison between more than two processes are not generally available.

There are many textbooks and handbooks that describe different manufacturing processes, their pros and cons, etc. Some handbooks even identify major factors that influence process selection and give qualitative guidance. Of the many sources available in print, perhaps the most comprehensive is by Bralla (1986). He gives an excellent coverage of major manufacturing processes, and comments on their suitability with respect to materials, mechanical properties, general shape and size, production volume, etc. While it is an outstanding handbook, he does not deal with the iterative nature of some of the decision factors such as production volume and cost (the more you make, the lower the price, thus more sales, etc.). Also the book documents the decision variables and the influencing factors in a “free format”. They are not completely uniform across different processes. This format sometimes makes it difficult to compare the suitability of one process to another. There are many other books that provide similar information with a focus on different processes. Ludema *et al.* (1987) look at the economic aspect of process selection, while Bolz (1974) combines mechanical requirements with cost issues. Eary and Johnson (1962) give a comprehensive coverage of a variety of manufacturing processes, but this information is now slightly dated.

Despite the abundance of literature on manufacturing processes and DFM methodologies for individual processes, very little work has been done in developing a computer-aid that accommodates information about different (old and new) processes, evaluates the suitability of each process with the designers’ needs, and assists in selecting the most appropriate process.

Process-based Group Technology represents the most notable attempt at guiding designers in process selection. Niebel (1966) devised a group technology system for a wide range of manufacturing processes. He also proposed a decision equation that approximates the cost per part of the primary operation. While his method gives a good “First cut” comparison of different processes, the system only addresses a relatively rough geometry classification (9 classes), materials, and lot size. Group technology normally addresses one classification factor, e.g., shape. Extending beyond one classification factor is not trivial. Therefore, group technology works well when it addresses a single process or processes that lead to similar geometry classifications.

1.3 The Proposed Approach

This paper focuses on single parts that are to be net or near net-shape manufactured. We first seek to identify the major factors that affect process selection at the early stages of design. Particular attention goes to decision variables that, in turn, affect original factors (e.g., materials affecting a process and process influencing detailed classification of materials, etc.).

The next step is to develop a representation scheme for knowledge about process selection. At different stages in product development, and depending on the amount of quantitative data available, engineers use a different type of knowledge in the selection process. At the very preliminary stage of design, engineers are likely to use more qualitative knowledge on compatibility between design specifications and the process than quantitative knowledge on life-cycle cost. The compatibility knowledge could be looked upon as good or bad templates of the design and process, i.e., case-based design rules. We call this approach “compatibility-based” or “case-based”, because the example cases of good or bad compatibility form the Knowledge Base. The framework of design compatibility analysis (DCA; Ishii *et al.* 1988) adopts primarily this type of knowledge representation.

As the design progresses and more data become available, designers can utilize a more quantitative form of compatibility information. One candidate form of compatibility representation is the interval information of various costs that leads to a ranking of different processes. For example, one may not be able to compare the exact part cost for each process. However, one can estimate the relative costs of different processes for a certain range of production volume by conducting the cost analysis for upper and lower limit of the range, i.e., use interval calculus. For example, die casting is more economic than powder metallurgy for a lot size of 5000 - 10000 interval. Current DFPS program adopts such type of compatibility representation. The most quantitative compatibility measure comes in the form of the life-cycle cost estimate.

The eventual goal is to combine these forms of compatibility information so that designers can utilize the most appropriate data at various stages of product development. This paper focuses on the first type of knowledge, case-based compatibility knowledge, and describes an expert system that uses qualitative and quantitative information to deduce a compatible set of manufacturing processes and provide a ranking among them.

2. The Decision Factors of Process Selection

2.1 Processes under Consideration

The current investigation covers the following net-shape processes:

1) Forging
2) Powder Metallurgy
3) Hot Extrusion
4) Sand Casting
5) Investment Casting
6) Die Casting
7) Injection Molding

2.2 Factors That Affect the Process Selection

The major factors that influence the process selection are classified to three categories:

(1) Material Factors:
(a) Mechanical Properties (stiffness, hardness, strength, etc.)
(b) Physical Properties (erosion resistance, melting temperature, etc.)
(2) Geometry Factors:
(a) Part Shape
(b) Part Envelope Size
(c) Part Weight
(d) Tolerances and Surface Finish
(3) Production Factors:
(a) Time to Market
(b) Production Quantity
(c) Production Rate

Material and Geometry factors of process selection are what people normally refer to as the functional requirement. Material selection is directly affected by material factors; however, some geometry requirements (minimum thickness, weight/size ratio, etc.) and the choice of the process also impose constraints. Again, we see some inter-dependencies in the parameters in production factors. The production rate and volume depend on the product sales and the market life (i.e., how long the product remains competitive on the market). The sales depend on cost which in turn affects production volume. Figure 1 shows the dependency between the factors related to product design and process selection.

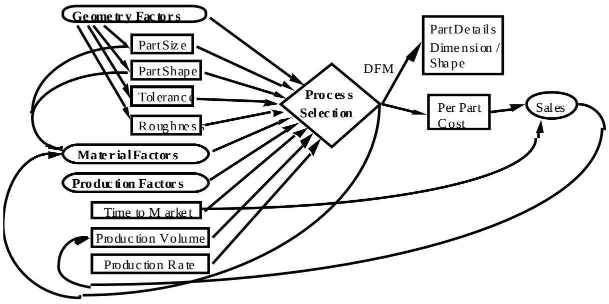


Figure 1. Design dependency diagram

This diagram views process selection as the main decision item with arrows indicating dependencies in the decision process. Note the cyclic dependency between 1) process and material, and 2) sales and production volume. The dependency between factors differs from product to product. This difference determines the sequence in which a designer would decide on the values of decision variables. In some cases, such as an electronics housing, the mechanical and environmental requirements give the designers a wide range of materials. Hence, the designers are likely to determine the process (injection molding or sheet metal forming) before deciding on the material. Naturally, the detailed design of the part and the determination of process parameters such as machine size and process conditions come after both the material and process selection. In essence, designers must resolve the eight major factors and select the appropriate process *simultaneously*. Let us briefly summarize how each major factor affects process selection.

1. Mechanical properties:
Mechanical properties such as stiffness (in one axis or several axes) and hardness have the biggest influence on part size and shape but they also have bearings on the process you chose. For instance, cold forging can have better mechanical properties than other processes because it can force the grain structure to follow the contour of the part.

2. Materials:
Material selection is perhaps the single most important factor in both part design and process selection. The material is primarily dependent on the physical and mechanical properties required. In actual practice, the following properties are considered: strength (tensile, compressive, shear, creep), hardness, corrosion resistance, thermal conductivity, stiffness, weight, melting temperature, etc. These material properties directly influence the production methods by which the material is worked. Each net-shape process is limited by the suitable materials. For example, in the die casting process, only low melting point metals such as zinc, aluminum, magnesium,

brass, lead and tin alloys can be used. Also, in die casting, metals with higher melting points still have problems even though they may become more and more economical as die materials are improved. On the other hand, there are cases in which the product drives the selection of materials, e.g., very thin walled die castings are typically manufactured from magnesium.

3. Part shape:
For geometrically simple parts such as bolts or straight shafts, the most economical method of manufacture is relatively apparent. As the shape of the part becomes more complex, selection of a suitable process becomes important. For example, cold forging is generally limited to cylindrical, square, hexagonal, or similar symmetrical shapes having solid or hollow cross sections. Therefore, if the part has an intricate and non-symmetric shape, a casting or molding process may be considered more suitable.

4. Part size:
The size and weight of the candidate designs also limit the selection of the process. For example, parts weighing more than 50 lb (22.7 kg) are usually difficult to produce using powder metallurgy (Trucks, 1987). In cold forging, the suitable weight of most parts ranges from 1 - 50 lb (0.45 - 22.7 kg), although the actual limits depend on the size and capacity of the press used.

5. Tolerances and surface finish:
While there are many types of tolerances and surface finish specifications, each process has inherent limitations. In fact, there is a range of tolerances for which each process can be employed most economically. Ludema (1987) shows the economical tolerance range in terms of size tolerances and typical component size. He also shows an economical range of surface finish. Note that tolerances are usually derived from assembly, mechanical, environmental, or aesthetic requirements.

6. Time to market:
People use time to market as an indicator of success. The shorter the time from concept to market, the more competitive the product. Nevertheless, the time to market is driven by 1) the time the product is expected to be competitive on the market, and 2) the existence of competition to develop similar products. Time to market may affect process selection since the short market life of the product may not warrant lengthy design and fabrication of complex tools. A short time to market may rule out injection molding over sheet metal forming despite a possibly large expected volume due to the long lead time for mold development.

7. Production quantity:
The production volume affects process selection to a considerable extent (Ludema, 1987). The cost of a process has break-even points over the economic production quantities. Figure 2 illustrates an example of how the production amounts would influence the method of process. In net-shape manufacturing, tool (die and mold) design and fabrication costs take a significant percentage of the production cost of the part. This percentage differs from process to process. For example, in the design of electronics housings, tooling for sheet forming (bending, folding, and stamping) will be significantly less expensive and less time consuming than tooling for molding.

8. Production rate:
Each process has its own possible production rate or an economical range of production rates although individual rates will differ depending on the machine capability. For example, the metal stamping process can produce parts at a rate of thousands per hour while the cycle time for injection molding is typically close to a minute.

3. Compatibility Knowledge Representation for Process Selection

For complex parts, there is generally more than one acceptable way of deploying a net-shape process to produce the part. Variations arise from the number and type of secondary operations required in the process plan. Additional machining or assembly operations may be necessary to add features which are difficult to form, to bring dimensional tolerances within limits, or to improve the micro-structural properties of the part. In the case of tolerances or additional features, it is sometimes possible to bring the part closer to a final shape with more complex and elaborate tooling or tighter process control. The use of more sophisticated tooling reduces or eliminates secondary operations but it entails tighter tooling costs and may involve higher operating and maintenance costs. The hypothetical cost vs. volume curve shown in Figure 2 illustrates the points at which the best processing choice will change. The issue is to identify the basic factors which control the location of such breakpoints and to establish methods to estimate the incremental tooling costs which determine them. Naturally, we must also incorporate into our compatibility consideration other factors such as mechanical properties and time to market

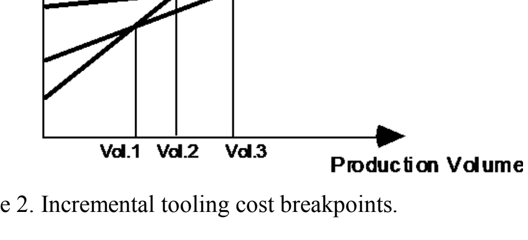


Figure 2. Incremental tooling cost breakpoints.

Most existing process selection procedures depend to a large degree on historical cost data. Such procedures have an inherent problem with maintaining current and accurate data. They are generally not useful for new processes or technologies which have no historical base. Further, accurate cost data only apply to relatively detailed stages of design. The main objectives of our research are: (1) to develop a representation scheme for the compatibility measure of a candidate process and (2) to construct a methodology to evaluate compatibility early in the design stage. This information tends to be rather uncertain in the early stages of design. Thus, our program must utilize qualitative, case-based knowledge that address the compatibility of each process with the product specifications.

In the following sections, we will be using the following notations:

X_i = Universe of discourse of the decision factor i

P = Universe of discourse of the process

$$XF = \prod_{i=1}^{n} X_i = X_1 \times X_2 \times \ldots \times X_n \quad \text{:decision factor spac} \tag{1}$$

where X is a subset of XF, i.e., $XF \supset X$

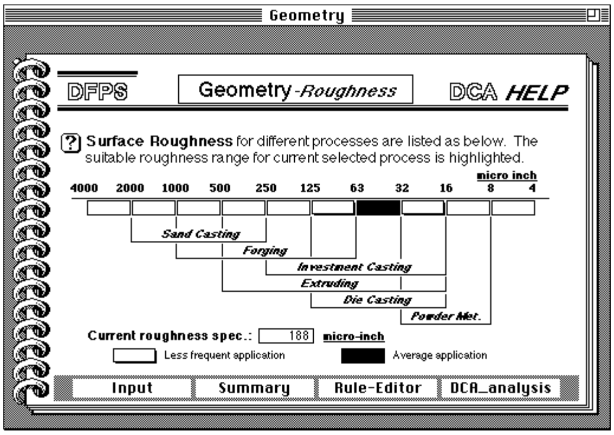
3.1 Case-based Compatibility Knowledge.

The first type of knowledge representation we propose is the case-based compatibility representation, i.e., good, poor, and bad examples of concept geometry and the selected process. An earlier paper on design compatibility analysis (Ishii *et al.* 1988) focused mainly on the qualitative design rules compiled as good and bad templates of design. Each template, called a C-data, has a qualitative rating (good, poor, bad, etc.), justification for the rating, and suggestions for improvement. The qualitative rating is later mapped to a number between [0, 1]. The template is grouped by the factor it addresses. The C-data comprise a set of data called the compatibility knowledge-base (CKB).

$$CKB = \{\, c-data \mid c-data \subset X \times P \times [0,1] \} \tag{2}$$

Equation (2) shows that the *CKB* is a set of relations between the decision factors and a candidate process. This yields a rating between 0 and 1. In our application, we use the adjectives [excellent, good, fair, poor, bad, incompatible] to represent the ratings [1.0, 0.8, 0.6, 0.4, 0.2, 0.0].

Let us give an example C-data related to surface finish. Figure 3 shows the surface finish capability of various manufacturing processes (Bralla, 1986). If the user specified surface finish falls in the "Average Application" of the capability range of a certain process, the compatibility is "Excellent." If the user input specification corresponds to the edge of the band, i.e., the less frequent application or if the requirement is less constrained, i.e., falls to the left of the range, then the compatibility is "Good". Obviously, if the specified surface finish is finer than the capability band, i.e, falls on the right of the band, the rating will be "Compatible."



Surface Roughness for different processes are listed as below. The suitable roughness range for current selected process is highlighted.

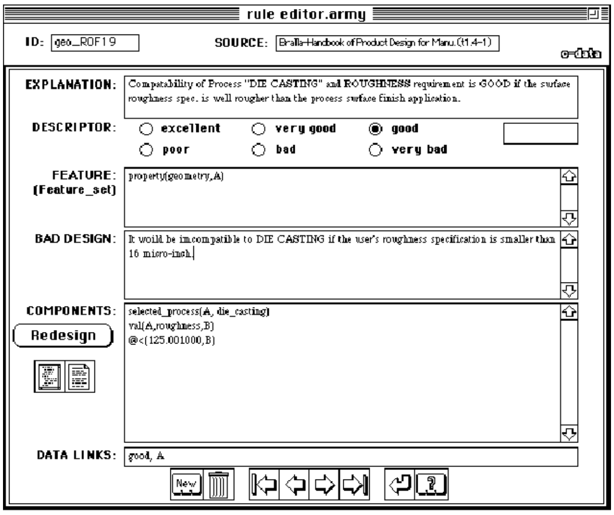
Current roughness spec.: 188 micro-inch

Figure 3. Surface finish capability of manufacturing processes (c.f. Bralla)

This qualitative information yields a set of C-data. Equation (3) logically represent an example of C-data.

C-Data (ID_number: geo_ROF19
Factor: Geometry
Descriptor: Good
Reasons: DCA of Process/Roughness is GOOD if user's roughness spec. is rougher than the average process surface finish application.
Conditions:
Selected_process = die_casting ing
Roughness_spec< 125) (3)

Figure 4 illustrates the C-data that indicates compatibility between die casting and surface finish specification of greater than 125 micro-inch. This figure is a representative of a typical C-data information card.



ID: geo_ROF19

SOURCE: Bralla-Handbook of Product Design for Manu.(t1.4-1)

EXPLANATION: Compatability of Process "DIE CASTING" and ROUGHNESS requirement is GOOD if the surface roughness spec. is well rougher than the process surface finish application.

DESCRIPTOR: ○ excellent ○ very good ● good ○ poor ○ bad ○ very bad

FEATURE: (Feature_set) property(geometry,A)

BAD DESIGN: It woild be imcompatible to DIE CASTING if the user's roughness specification is smaller than 16 micro-inch.

COMPONENTS:
selected_process(A, die_casting)
val(A,roughness,B)
@<(125.001000,B)

DATA LINKS: good, A

Figure 4. Example C-data in a compatibility knowledge-base.

3.2 Use of DCA in Deducing a Ranked Set of Candidate Processes

Design compatibility analysis (DCA) measures the compatibility between the decision factors and the candidate process. For each of three categories (i.e. material, geometry, and production), DCA compiles the compatibility object that "matches" a particular situation then takes the most extreme rating (i.e., if there is more than one "negative" comment, DCA takes the worst comment; otherwise, it will adopt the best comment). If no compatibility data matches, DCA gives a neutral value. In Ishii (1988), the neutral status was assigned a match index of 0.5 (the index was normalized between 0 and 1). Hence,

$$\textbf{DCA}: \quad X \times P \times CKB \rightarrow [0,1] \tag{4}$$

That is, DCA is a mapping from the decision factors, the candidate process, and the compatibility templates to a normalized evaluation. Therefore, we obtain three sub-ratings from material, geometry, and production factors. The overall match index is defined as

$$MI_{overall} = \sqrt[3]{\prod_{i=1}^{3} M_i} \tag{5}$$

We previously used the arithmetic average of the three sub-ratings as the overall match index (Ishii *et al.* 1991); however, we adopted the current definition after some field testing. Most engineers who tested the initial program felt uncomfortable when they saw a non-zero score with a process which was clearly incompatible with at least one of the specifications. This change enables DCA to give a zero overall match index whenever there exists any totally incompatible factor with the process in the user's specification.

Figure 5 shows the schematic of DCA using case-based compatibility rules. The figure illustrates the "simultaneous" nature of the evaluation process. Once the user specifies the values of various decision factors such as production volume and surface roughness, DCA scans through the compatibility knowledge-base for each candidate process and determines which C-data matches. In some cases, only positive comments match, while for others there may be found several totally incompatible C-data which apply. Based on the number and the nature of applicable C-data, DCA determines a sub rating for each factor category and evaluates the geometric average of the three sub ratings for the overall matching index. In short, the rating scheme is:

1) Sub rating M_i for each factor category
   a) 0.5 if no C-data matches
   b) The sub rating that corresponds to the worst adjective, if there is at least one negative comment in this category
   c) The sub rating that corresponds to the best adjective, if there are no negative comments in this category
2) Overall matching index
   $MI_{overall}$ is the geometric average of the three sub ratings M_i.

This method has proven its effectiveness in the very early stages of design often when there is little quantitative cost data available. We view this overall matching index to be a normalized estimate of production cost per part. For details of DCA, refer to Ishii *et al.* (1988) and Ishii and Nekkanti (1989a).

The idea behind our expert system for screening of potential manufacturing processes is to use DCA to rate each candidate. For those compatible processes, designers may want to focus on the top two or three candidates and proceed with detailed analysis based on these processes. Therefore, from the appropriate C-data, they can identify key factors inducing a poor rating. Designers have the option to either relax unnecessary specifications or look for an alternative process to improve the design manufacturability. As more detailed information becomes available, designers may wish to employ a more quantitative measure of process compatibility such as cost estimate intervals (Ishii, Ho, and Miller, 1990).

Nevertheless, the screening procedure based on case-based knowledge will provide the designer with a focused view on possible manufacturing processes and encourage him to consider tailoring part designs for the candidate processes. Such consideration will greatly enhance design for manufacturability and reduce life-cycle cost of products under development.

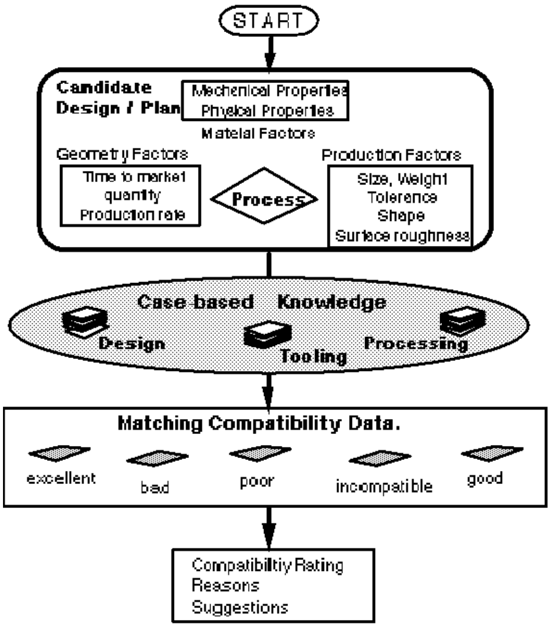


Figure 5. Schematics of Case-based DCA

4. Implementation of DFPS

We have implemented our proposed procedure using HyperCard and Prolog. The prototype program, called DFPS is structured as illustrated in Figure 6.

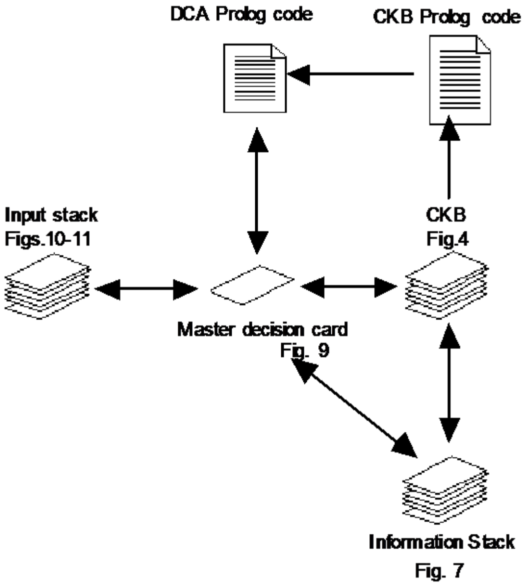
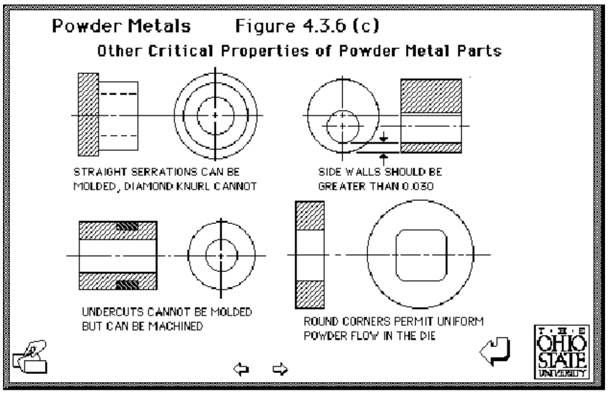


Figure 6. Program Structure of DFPS

The current version utilizes Logic Manager, an implementation of Prolog developed by Apple Computer. The DFPS rule base consists of over 100 C-data, in addition to over 30 inference rules related to characteristics of each manufacturing processes.

In addition to the selection feature using DCA, the program incorporates a library of process information for net-shape manufacturing. This information is organized as an HyperCard information stack. Figure 7 shows an example card out of this information stack.



Powder Metals Figure 4.3.6 (c)

Other Critical Properties of Powder Metal Parts

STRAIGHT SERRATIONS CAN BE MOLDED, DIAMOND KNURL CANNOT

SIDE WALLS SHOULD BE GREATER THAN 0.030

UNDERCUTS CANNOT BE MOLDED BUT CAN BE MACHINED

ROUND CORNERS PERMIT UNIFORM POWDER FLOW IN THE DIE

Figure 7. An example card from DFPS information stack

5. Example Run of Program

This section gives an example case of how DFPS can be used to find an appropriate process for a given part design. Figure 8 shows a proposed part design. The specified material is aluminum alloy, the minimum dimensional tolerances is of ± 0.01 inch (± 0.254 mm), The estimated production volume is 3000 pieces, and the surface finish requirement is 50 micro-inch (1.27 micro-meter).

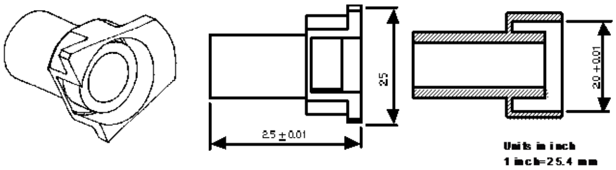


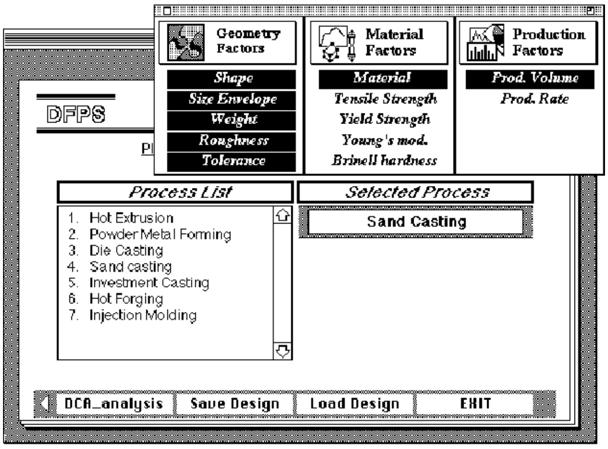
Figure 8. Example Part

Figure 9 shows the master input card in DFPS which navigates the user to various specification input modules and help files. This card accepts the user inputs in three modules: 1) material factors, 2) geometry factors, and 3) production factors. DFPS accepts these inputs through user interaction cards. Examples of these cards are shown in figures 10 and 11.

After the user specifies the required input variables, DFPS uses case-based knowledge and DCA to screen each process and suggest alternative processes based on the design factors previously mentioned in section 3.2. In our example, DCA deduces three suggested processes and displays the results in an output card as illustrated in Figure 12. Die Casting, and Investment Casting satisfy the specifications of dimensional tolerances, surface finish, material selection, and production quantity requirements, while Investment Casting gives the better total match index. Designers can perform a detailed DCA for a selected process by clicking on the process list shown in Figure 12. A DCA card with overall matching index, sub ratings for each of the three factor categories, and all the C-data triggered is shown in Figure 13. Designers can then identify the key factors producing the rating. Some modification of the specifications could be attempted to improve the matching index or to adopt some other processes. A visual on-line help for each C-data used is also furnished (shown in Figure 3 and Figure 14) to help users modifying their design.

This example illustrates the trade-off between production cost and dimensional accuracy in die casting, powder metallurgy, and investment casting. Die casting can achieve tighter tolerance and surface roughness than investment casting but the cost will be much higher for the estimated production quantity of 3,000 pieces. This is because die casting is only good for mass production (usually more than 5,000 parts) since the initial investment for tooling is large. Therefore, it would not be economic to use die casting for this case. We can see the same concern raised for powder metallurgy. Besides, because aluminum alloy is not frequently used in powder metallurgy, additional technique cost might be incurred for this process.

This kind of case-based knowledge allows the designer to carefully look back at the design specifications and reconsider whether some of the design factors can be changed without sacrificing any functions of the part. For example, if dimensional tolerance can be relaxed to ±0.02 inch and surface roughness can be relaxed to 63 micro-inch, then hot forging can be added to the list of candidate processes. Now, if the tolerances were tightened to ± 0.005 inch, investment casting would no longer be acceptable. However, a two step process plan with investment casting followed by machining may be cost effective. The use of investment casting as the primary process would minimize the amount of material to be removed resulting in lower total cost than machining from raw stock or using high dimension accuracy like powder metallurgy. Similar arguments may apply for forging and other processes.

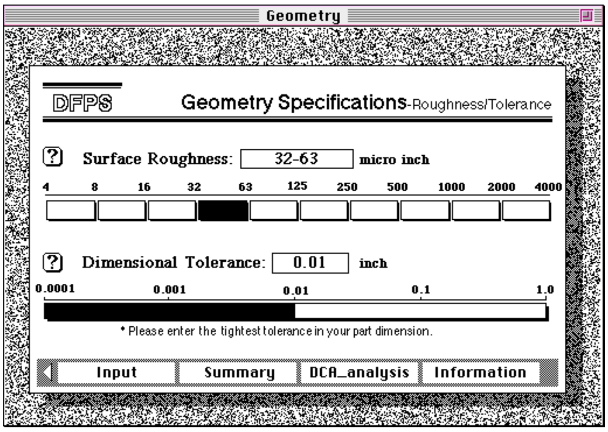


Process List

1. Hot Extrusion
2. Powder Metal Forming
3. Die Casting
4. Sand casting
5. Investment Casting
6. Hot Forging
7. Injection Molding

Selected Process: Sand Casting

Figure 9. Master Input Card in DFPS



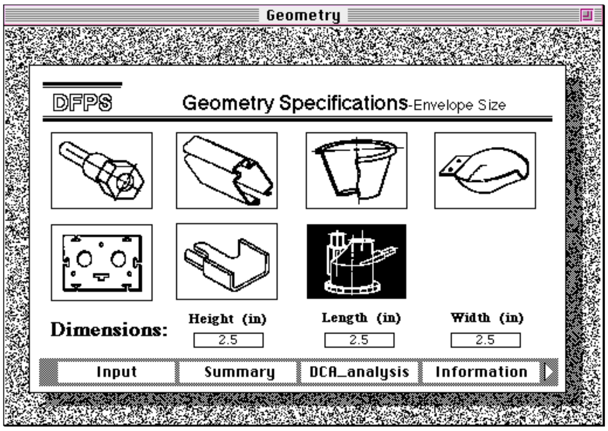
Geometry Specifications-Roughness/Tolerance

Surface Roughness: 32-63 micro inch

Dimensional Tolerance: 0.01 inch

* Please enter the tightest tolerance in your part dimension.

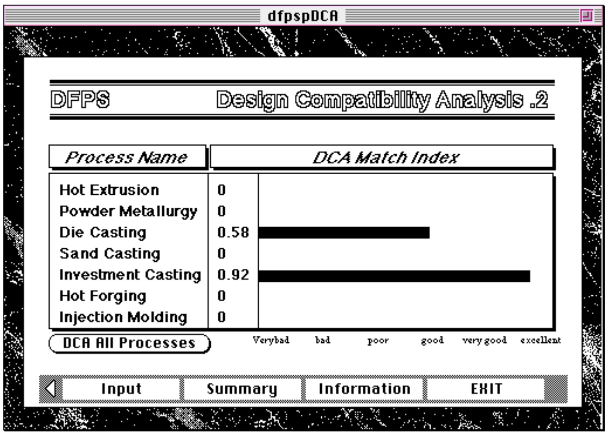
Figure 10. Surface Roughness/Tolerance specification card



Geometry Specifications-Envelope Size

Dimensions: Height (in) 2.5 Length (in) 2.5 Width (in) 2.5

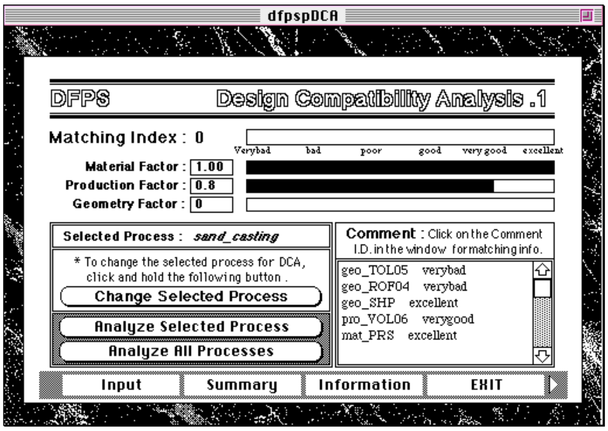
Figure 11. Part shape classification/Envelope size specification card



Design Compatibility Analysis .2

Process Name	DCA Match Index
Hot Extrusion	0
Powder Metallurgy	0
Die Casting	0.58
Sand Casting	0
Investment Casting	0.92
Hot Forging	0
Injection Molding	0

Figure 12. Process ranking card



Design Compatibility Analysis .1

Matching Index : 0

Material Factor : 1.00

Production Factor : 0.8

Geometry Factor : 0

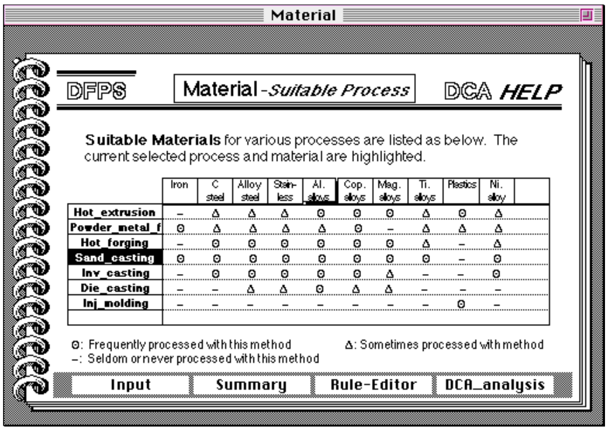
Selected Process : *sand_casting*

* To change the selected process for DCA, click and hold the following button .

Comment : Click on the Comment I.D. in the window for matching info.

geo_TOL05	verybad
geo_ROF04	verybad
geo_SHP	excellent
pro_VOL06	verygood
mat_PRS	excellent

Figure 13. Detailed DCA for Selected Process



Suitable Materials for various processes are listed as below. The current selected process and material are highlighted.

	Iron	C steel	Alloy steel	Stain-less	Al. alloys	Cop. alloys	Mag. alloys	Ti. alloys	Plastics	Ni. alloy	
Hot_extrusion	–	Δ	Δ	Δ	⊖	⊖	⊖	Δ	⊖	Δ	
Powder_metal_f	⊖	Δ	Δ	Δ	Δ	⊖	–	Δ	Δ	Δ	
Hot_forging	–	⊖	⊖	⊖	⊖	⊖	⊖	Δ	–	Δ	
Sand_casting	⊖	⊖	⊖	⊖	⊖	⊖	⊖	⊖	–	⊖	
Inv_casting	–	⊖	⊖	⊖	⊖	⊖	Δ	–	–	⊖	
Die_casting	–	–	Δ	Δ	⊖	Δ	Δ	–	–	–	
Inj_molding	–	–	–	–	–	–	–	–	⊖	–	

⊖: Frequently processed with this method
Δ: Sometimes processed with method
–: Seldom or never processed with this method

Figure 14. DCA online help for process/material compatibility

6. Conclusion and Future Work

This paper covered our proposed methodology for process selection that applies to early stages of product design. We focused on net-shape manufacturing processes and identified the major factors that affect the selection of an appropriate process. Some of these decisions are iterative. The sequence in which designers typically base decisions depends largely on the nature of the product and the development environment. Thus, we concluded that our methodology should consider all the factors *simultaneously* in assessing the suitability of the candidate processes.

The paper then described the compatibility representation of various processes to a given set of specifications. In particular, we focused on case-based knowledge: templates of good, bad, and poor combination of decisions. This type of knowledge is appropriate for early stages of design when many influencing factors are uncertain.

This case-based representation of process selection knowledge lead to the development of DFPS, an expert system based on design compatibility analysis (DCA). DFPS, a HyperCard-based program, uses Prolog to deduce a rated set of compatible manufacturing processes for a given set of product specifications. The program also includes a HyperCard stack which stores process information in an object-oriented fashion and allows users to search though the stack using a navigation map.

So far, we only use handbook rules which might be shallow in scope but still useful for young engineer training purposes. We see many areas for improvement. An immediate future task is to incorporate deeper rules in compatibility knowledge such as cost model and sensitivity analysis. As part designs progress, engineers have access to more quantitative cost information for various candidate processes. Our challenge is to combine these more quantitative cost models with the case-based, qualitative compatibility measures as designs become more detailed and quantitative measures become available.

Another aspect we must consider is the modularity of parts. A proposed part may at times be more efficiently produced if it were broken up into two parts and manufactured separately. This question of modularity is a tradeoff between assembly cost and production cost per part. Yet another factor is the combination of processes. Rather than producing a working component in one process, a combination of net-shape process and a finishing process may yield more efficient overall production while maintaining the specified quality. The key here is the overall optimization of production costs that take into account not only the component manufacturing cost but also assembly, service, and perhaps even recycling cost.

Our long range goal is to develop an integrated design assessment tool for net-shape manufacturing based upon qualitative compatibility and quantitative cost and sensitivity analysis. In the early stages of design, the approach outlined here only requires classification of part geometry. As the design progresses and as designers seek a more accurate cost estimate, our tool needs to account for the characterization of geometry that affects process selection. We propose to enhance future versions of DFPS by adding a sketching enviroment. This will allow the user to input/import part designs in a more efficient manner. DCA will then be preformed upon the design. Current investigation focuses on manufacturing processes for Aluminum alloys and PVC. This level of detail will require us to integrate our method with an advanced geometry modeling environment.

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