A Method for Improving the Producibiiity of Precision Planar Stamped Products

by

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Abstract

This report describes the development of a new computer-based environment which will help a designer of stamped products to improve producibility of a proposed initial design through a design evaluation and redesign process. The main idea in the current producibility evaluator is that it is structured to incorporate the effect of specific design specifications on their subsequent manufacturing costs. In this manner, the product designer can make the decisions as to whether the functionality of various design specifications are worth the necessary high manufacturing costs.

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INTRODUCTION

This report discusses a new methodology for the evaluation and maximization of the producibility of stamped products. The main thrust of this work is to aid product designers in developing planar stamping designs, such as lead-frames, which can be manufactured as cheaply, reliably and with as few time delays as possible (i.e. with high producibility). By using an interactive, modular computer environment, consisting of a CAD solid modeler, a Geometric Reasoner, and an Expert System, the user will be fedback design evaluation results and redesign suggestions for improved product producibility (see Fig. 1).

An earlier report (1) discussed a very simple, preliminary version of such a computer evaluation package.

The original evaluation system, however, had several shortcomings:

1) the evaluation was completely based purely on the final design, without regard to the dies and punches required to stamp the part;

2) complex designs, such as lead-frames, could not be handled;

3) the simple pass/fail structure of the system gave no measure of how "good[11] a design was.

A more indepth study of all aspects of the stamping process, from initial design evaluation, to strip layout, to die design, to process limitations, showed that simply testing a design for manufacturability (i.e. whether or not a designed part can be stamped) is only a portion of design evaluation important to the product designer. Also important to the designer is the producibility of the product which is defined as the measure of the manufacturability, time, reliability, press requirements, and overall manufacturing costs associated with stamping a part from a product design.

Thus, the new design evaluation methodology described in this report incorporates all this key information. A set of Manufacturing Cost Factors are defined, which collectively reflect design producibility. To calculate these cost factors, the design is first structured as a set of manufacturing features (such as holes). Cost Functions are then defined to take as input key manufacturing feature parameter values (such as hole diameters), along with the set of secondary design specifications (such as part material properties), then predict the stamping process requirements and press and part material behaviors, and finally output cost factor values. Because these Cost Functions are defined such that the input is a known design parameter, the design specifications responsible for the high cost factors can be output to the user. In this manner, the designer can make the decision of whether each design specification's functionality is worth the associated manufacturing cost output by the system. Redesign suggestions to lower the manufacturing costs (i.e. to raise overall producibility) are also output.

Finally, because the design refinement process described above is completed at a single workstation, the time and costs associated with future redesigns is minimized.

The report is organized as follows: Section I deals with the objectives of the current phase of project work; Sections II. though IV. discuss the work done to meet these objectives; Section V. shows a simple example of evaluating a stamping design using the current approach; Sections VI. and VII. discuss current capabilities and work yet to be done; finally, a project summary is given.

L Objectives

The objectives for developing the modified Producibility Evaluation Package (P.E.P.) are as follows:

1) Obtain a rigorous definition for design producibility by which designs can be measured.

2) Determine how domain experts assess the producibility of a proposed design.

3) Structure the domain knowledge in such a way that the Expert System module (in Fig. 1) can also carry out the evaluation process.

4) Enhance the Geometric Reasoner module so that it can obtain the necessary data from the Solid Modeler module (see Fig. 1).

Each of these objectives has been met, and the work done to meet these objectives is discussed.

U Defining Producibility

The producibility of a stamped product is a measure of the feasibility of stamping the designed part reliably, at low cost, with minimal labor and maintenance, and with a low design-manufacturing cycle time. More specifically, this design producibility is made up of a set of Manufacturing Cost Factors (M.C.F.). It is proposed that the overall producibility can be assessed by determining these M.CJF, Moreover, minimizing these M.C.F. as a set will maximize producibility. Thus, to maximize producibility, the task is to identify all M.C.F., and calculate exact or relative values for each M.C.F. so they can then be minimized through design modifications.

More specifically, the stamping costs can be expressed in terms of the following Manufacturing Cost Factors:

1) Secondary Operations (e.g. drilling, deburring)

2) Tool Replacement Costs

3) In-Process Inspection Time

4) Necessary Die Inserts

5) Stripper Costs (e.g. necessity of pressure pads)

6) Number of Punching Tools

7) Number of Progressions

8) Material Scrap

Note this is not an exhaustive list, but it does represent those costs which can directly be controlled through design alterations. Because calculating absolute values for a design's overall producibility involves many more contributing factors, a precise numerical value for a design's producibility (i.e. total manufacturing labor, costs, reliability) is not sought. Thus, because the goal is to maximize producibility, only relative quantities for the M.C.F. are necessary.

IEL Assessing a Design's Producibility

In order to capture the reasoning used in producibility calculations, a complete study of all aspects of stamping, from die design, to process limitations, to part material behaviors, is necessary. In this manner, all the cause-effect relations, from design, to press requirements and process behaviors, to Manufacturing Cost Factors, become known, thus allowing one to trace the design source of each Manufacturing Cost Factor's values.

To understand these links from design to M.C.F., several more definitions are required:

1) Manufacturing Features (M.F.) - the set of part components defined such that manufacturing reasoning can be performed on the design (see Fig. 6):

a) Holes (with sub-features such as legs, notches, and corners)

b) Blanking Contour (the outer part contour, with sub-features such as legs, notches, and corners)

c) Intermediate Webs (the material between holes and the blanking contour)

2) Secondary Specifications (S.S.) - the set of design specifications accompanying the part design:

a) Material Properties of the Part

b) Number of Runs Desired

c) Tolerances

3) Process Variables (P.V.) - The physical parameters which govern the process limitations and costs of stamping. These Process Variables, along with the Secondary Specifications, are the basis for all cost calculations:

a) Die Stresses

b) Part Stresses

c) Punch Stresses

d) Punch Manufacturability

e) Die Manufacturability

f) Complexity of Die/Punch Cross-Sections

4) Intermediate Cost Factors (I.C.F.) - the set of adverse physical consequences suffered in stamping a part in a non-ideal manner:

a) Burr Formation

b) Tool Wear

c) Tool Breakage

d) Die Wear

e) Die Breakage

f) Part Distortion

The inter-dependence of these quantities is shown in Fig. 2, revealing the complex networking to step from design (i.e. Manufacturing Features and Secondary Specifications) to Manufacturing Cost Factors. Basically, each M.C.F. is not only a function of all the other parameters, but also at times of other M.C.F.'s. These functions are called Cost Functions:

(M.C.F.)i = fi (M.F., S.S., P.V., I.C.F., M.C.F.),
fj: Cost Functions
(i = 1,2,....8) since we have chosen to consider 8 Manufacturing Cost Factors.

An example of a Cost Function is shown in Fig. 3. The basic strategy used in assessing a design's producibility is to determine if the part can be stamped such that all Manufacturing Costs Factors are at their minimum value. Thus, considering the example in Fig. 3, the following steps are taken in this evaluation process:

1) From the Manufacturing Features and Secondary Specifications determine the Process Variables (e.g. from the part material shear strength and part geometry, determine the resulting Tool Stresses).

2) From the Process Variables and Secondary Specifications, determine the Intermediate Cost Factors (e.g. from the Part Stresses, determine the Part Distortion).

3) From the Intermediate Cost Factors, Process Variables, and Secondary Specifications, and sometimes other Manufacturing Cost Factors, determine the values for the Manufacturing Cost Factors being studied (e.g. from the Tolerances, potential Burr Formation, Tool Breakage, and Part Distortion, determine if any Secondary Operations are required).

Again, all Manufacturing Cost Factors values can be traced back to the Manufacturing Features and Secondary Specifications from which they arise. Thus, if a Manufacturing Cost Factor is high, the manufacturing engineer can indicate the region of the design in question (e.g. a specific hole). The designer can then interpret the design area in question in terms of its functionality, and in this manner, he can make the ultimate decision on whether the functionality is worth the resulting stamping costs. This flow of design information, from functional specifications, to part design, to manufacturing requirements and costs, and back again, is shown in Fig. 4.

It should be noted that this structuring of the evaluation process reflects the ideal sequence of events in proceeding from part design to manufacturing requirements. However, in real practice, many of the Process Variables and Intermediate Cost Factors are not exactly calculated. For example, precise values are not obtained for part stresses incurred during stamping. There are simply too many variables which affect the stress conditions that even complex finite element calculations would be meaningless.

Instead, stamping engineers follow guidelines which capture the critical parameters governing process limitations. For example, designs with sharp corners are empirically known by stamping engineers to be avoided because of the resulting die stresses. Thus, instead of calculating the precise stress distribution in the die, stamping engineers can predict the behavior of the die by very simply knowing stress concentration values..

IV. Structuring the Produdbility Evaluation Package

The P.E.P. should carry out a design evaluation just as manufacturing engineers do, as described in Section HI. However, there is a fundamental problem in developing such an evaluation system. A close look at the Manufacturing Cost Factors reveals that reasoning must be done on the punches and dies required to stamp the part. As stated earlier, only the final part design, along with any Secondary Specifications, is input to the P.E.P. Thus, there must be a method of mapping the part to the required punches and dies. Indeed such a mapping can be created if the design is restructured in terms of the set of Manufacturing Features defined earlier.

Because the evaluation system first determines if each Manufacturing Cost Factors can be at its minimum value, the Number of Punches is first assumed to be a minimum (i.e. each hole is pierced with one punch, the blanking contour is blanked with one punch). Also, the Number of Stations is assumed to be one. With this initial assumption, a convenient part to die/punch mapping is possible, and thus the system can reason in the punch and die domains (see Fig. 5).

If it is determined that the Number of Punches cannot be a minimum, die mapping becomes more complex. The P.E.P. must be able to automatically determine the new punch and die cross-sections, which no longer exactly match hole, blank contour, and web cross-sections.

For example, consider the hole to be pierced shown in Fig. 6. Because of Punch Manufacturability considerations (see Section V), a single punch cannot pierce this hole. In fact, three punching tools are required (see Fig. 7). The P.E.P. must be able to determine these new tool cross-sections and therefore the new mapping between the hole cross-section and the required punches so that later reasoning can be performed in the punch and die domains..

With this in mind, the P.E.P. is structured as follows:

1) Using the Geometric Reasoner, identify the design's Manufacturing Features, and extract all the necessary attribute values. Also accept any Secondary Specifications values.

2) Using the Cost Functions and the domain mapping schemes, determine the Manufacturing Cost Factors values required to stamp the part.

3) For all Manufacturing Cost Factors that are not at their ideal values, output the following information:

a) the M.C.F. in question;

b) the cause for its value being high (i.e. the M.F. attribute value or S.S.);

c) redesign suggestions to lower the M.C.F.

V. A **Sample Evaluation Run**

A small portion of the steps carried out by the P.E.P. in evaluating a simple planar stamping will be considered. What will be discussed is the calculation of the Number of Punching Tools required to pierce the hole in a portion of a lead-frame (see Fig. 6). The results of the three-step evaluation process are shown in Figs. 7-8.

A few subtle points, which show the complex nature of the necessary reasoning, are worth discussing:

1) In calculating the total Number of Punches required to pierce Hole 1, the Expert System initially determines that there are three areas of Hole 1 (i.e. Notch 1, Corner 1, Corner 2) which must each be stamped by two separate punching tools (see Column 5 of the evaluation table in Fig. 8). However, all of Hole 1 only requires three punches to pierce, not the six implied by the three areas of Hole 1 (see Fig. 7). This is an example of a case where the P.E.P. must be able to breakdown a single punch cross-section, having the same cross-section as a complete hole, into the minimum number of necessary smaller punches.

2) As seen in Column 2 of the evaluation table (Fig. 8), a single sub-feature attribute value, namely the radius of curvature of Corner 1, causes three distinct problems: high Die Stresses, high Punch Stresses, and a failed Punch Manufacturability test. Also, each problem has its own corresponding redesign suggestion. This is an example of how a single design parameter can lead to numerous manufacturing

Also, each problem has its own corresponding redesign suggestion. This is an example of how a single design parameter can lead to numerous manufacturing problems.

3) Continuing with Corner 1, notice that in Column 6 of the table there are two different redesign suggestions, namely setting r = 0.010" and setting r = 0.015", but only the latter is output to the designer. In general, all possible redesigns need to be output, giving the designer the flexibility of all choices. However, in this case, setting r = 0.010" would not lower the Manufacturing Cost Factor, the Number of Punches, and thus it is not output as a redesign suggestion. To understand this reasoning, the effects the Manufacturing Cost Factors have on each other (not explicitly shown in the evaluation table) must be considered.

Corner radii, in affecting Punch and Die Stresses, also affect the Tool Replacement and Inspection Costs. In this case, for corners with r < 0.015", the increase in the Tool Replacement and Inspection Costs produces higher total costs if the Number of Punches is set to one, than would be the extra cost of setting the Number of Punches to three, with the Tool Replacement and Inspection costs being minimal. In other word, if the radius is set to r = 0.10", a single punch can be made to pierce the hole, but the ensuing Tool Replacement and Inspection Costs would be so high that it would be less costly (i.e. more producible) to use three punches. Thus, to output a suggestion of setting r = 0.010" would be meaningless, since this suggestion does not improve the producibility of the design (i.e. it does not lower the Number of Punches). This is an example of how the Manufacturing Cost Factors are not independent of each other.

VI. Current Capabilities

Discussed below are the stages of developing the P.E.P. which have been accomplished:

1) The Geometric Reasoner is now able to perform the following tasks automatically for all possible planar designs (i.e. constant thickness, three-dimensional designs), with no flagging burden imposed on the user:

a) Locate all holes and webs, and the blanking contour.

b) Determine all hole diameters and widths, including leg and notch widths.

c) Determine all blanking edge widths, including notch and leg widths.

d) Determine all web widths.

e) Find all notch concavities.

2) Much of the domain knowledge, including the Cost Functions discussed earlier, has been collected and structured for producibility calculations.

VII. Future Work

More work needs to be done in order to complete a working version of the P.E.P.:

1) The domain knowledge acquisition and structuring needs to be completed such that the complex Cost Functions can be implemented and incorporated in the revised Expert Systems.

2) A method for handling corner radii of curvature with the linear solid modeler must be determined. Two potential solutions are being investigated:

a) radii flagging at the designer's CAD system level, which would accompany the model after it becomes linearized by DFMSOLID.

b) a user-interactive mouse used to flag radii after the model is linearized.

3) A means of communicating evaluation results about specific design features must be derived. A visual highlighting scheme is being investigated.

4) Absolute values for design producibility, in terms of total cost and labor requirements, should be calculated so that the total manufacturing investments required for stamping the part can be compared with other potential manufacturing methods.

SUMMARY

In this report we discussed a design development methodology which will maximize a design's producibility, while maintaining design functionality. An initial design is entered into the P.E.P. for evaluation, and design suggestions are output. The key concept in this implementation is that the P.E.P. points out to the designer exactly what areas of the design will cause manufacturing problems and high costs. In this manner, the designer himself can weigh the importance of each functional specification against manufacturing costs. Most importantly, this design evaluation and redesign can all be accomplished by the product designers at a single workstation, before any manufacturing commitments are made. The design-manufacturing cycle time will also be reduced, since the final design arrived at using the P.E.P. should minimize and possibly eliminate future redesigns.

ACKNOWLEDGEMENTS

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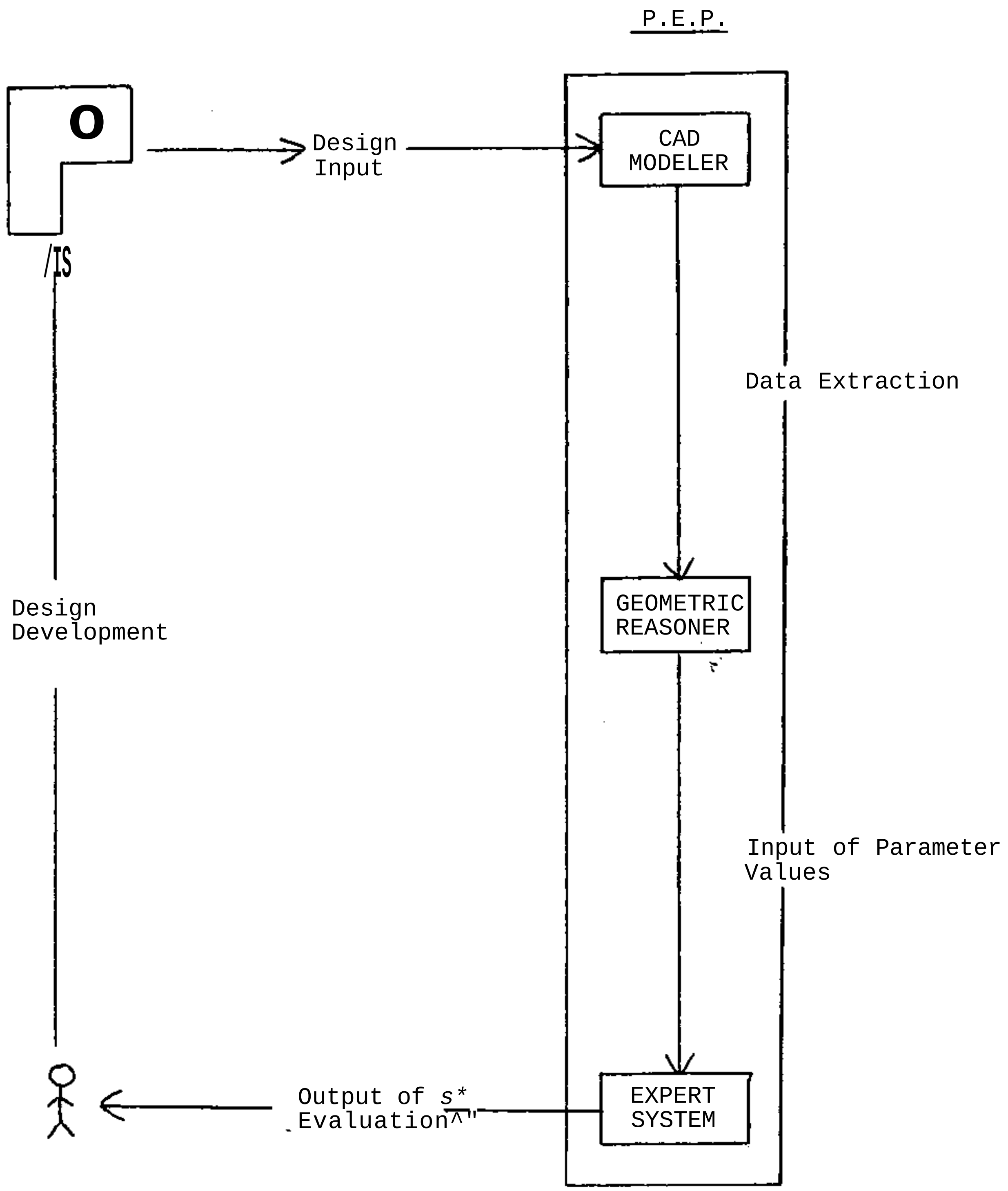

Note: The CAD system utilizes DFMSOLID, developed at the Design for Manufacturability lab, EDRC, at Carnegie Mellon University

Fig.1 Design Evaluation Process

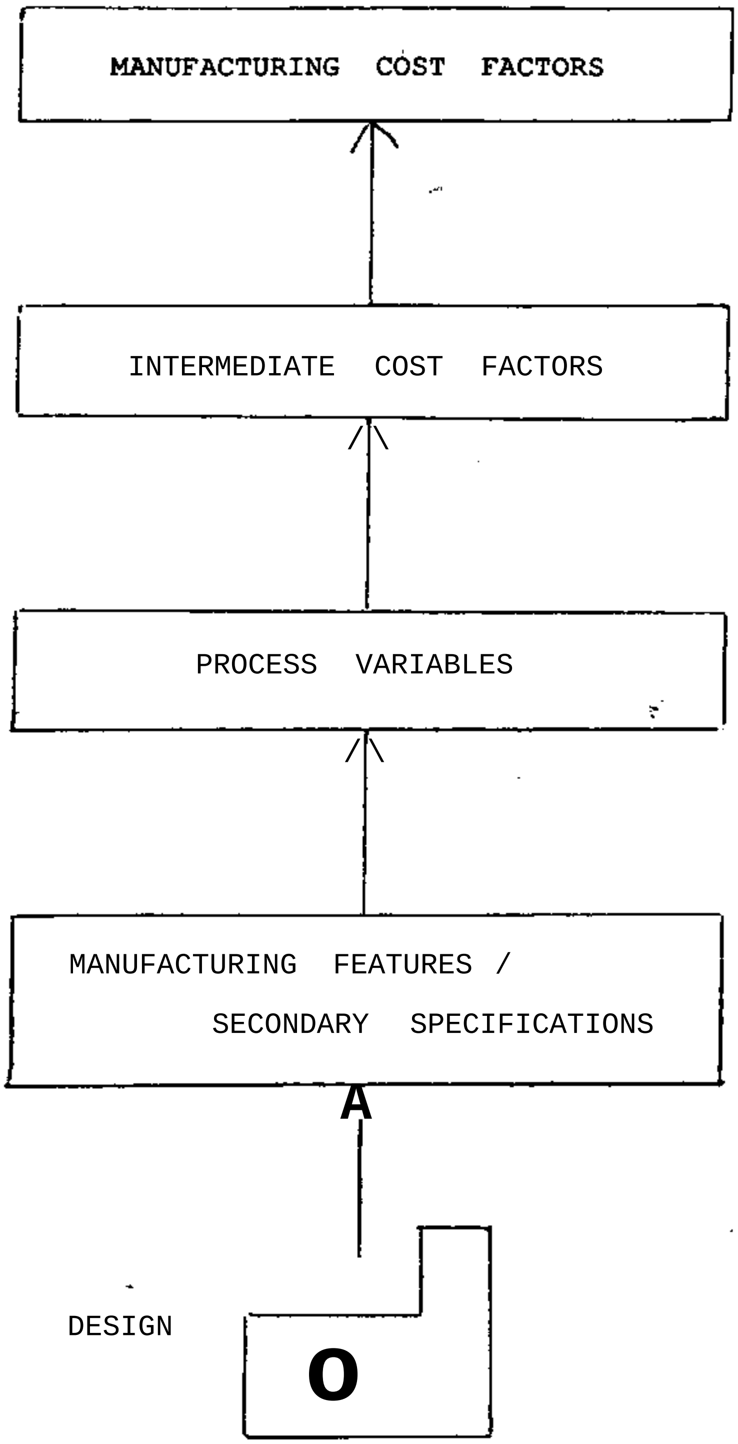

Fig.2 Networking From Design to Manufacturing Costs

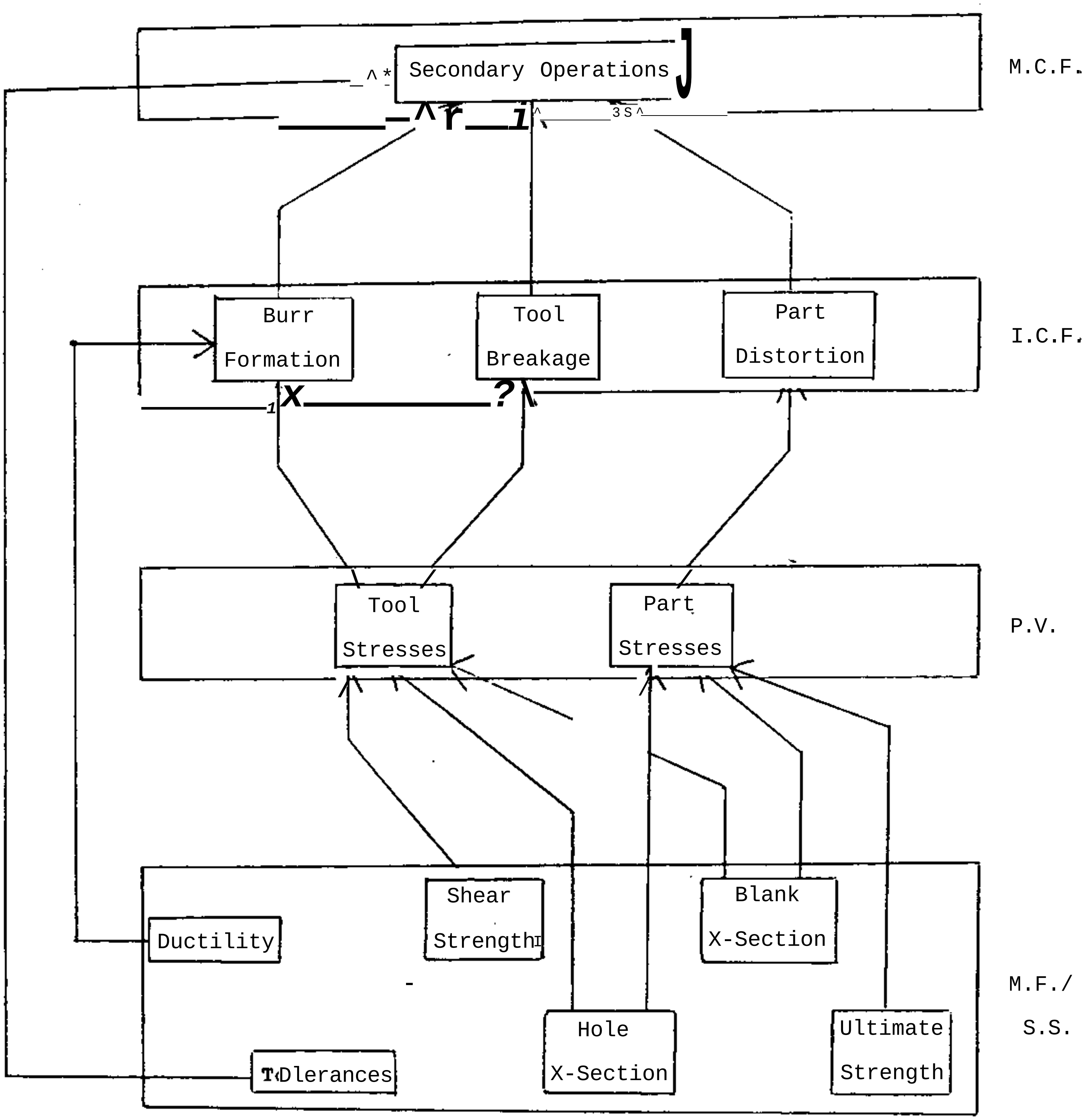

Fig.3 An Example of a Cost Function

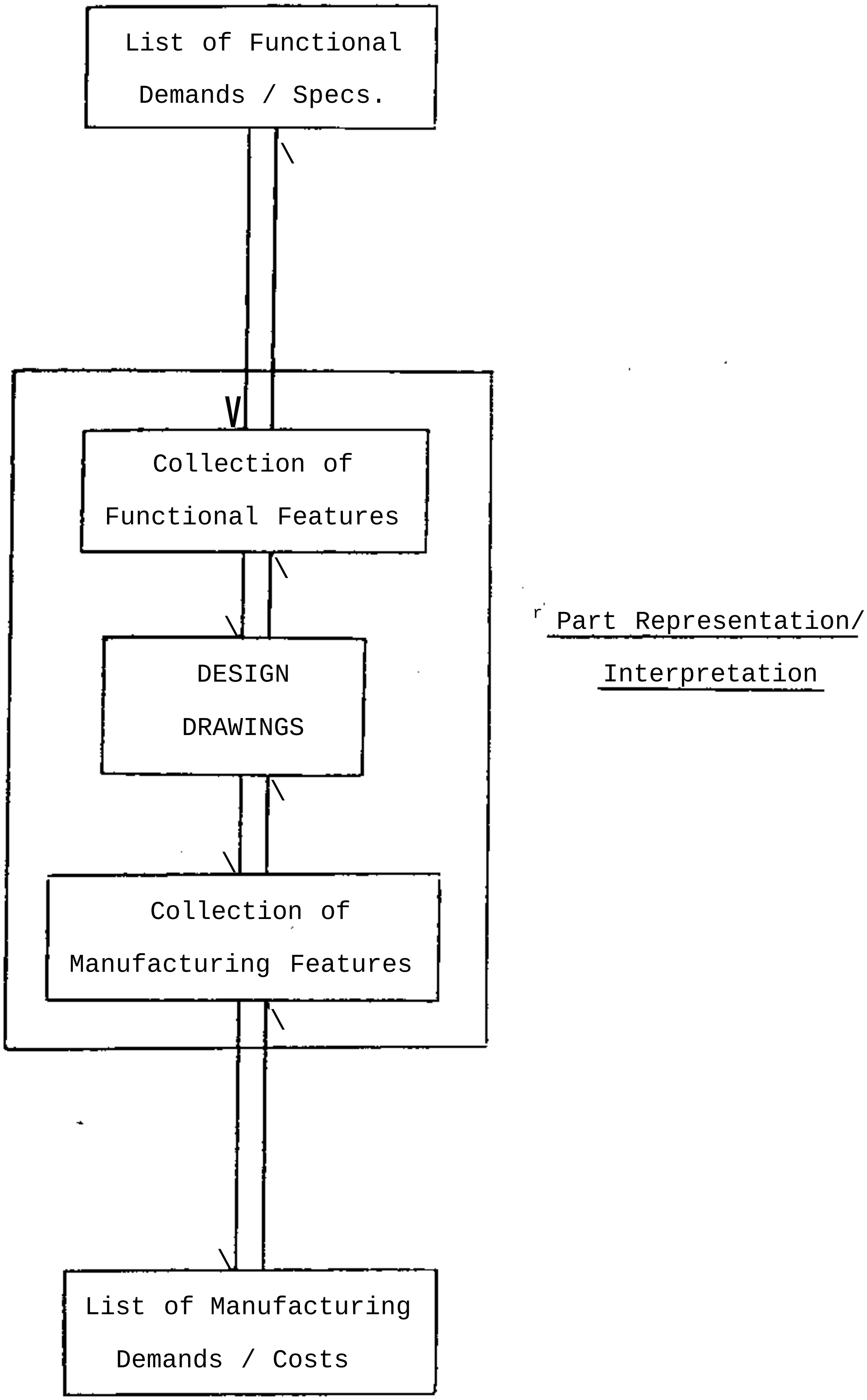

Fig.4 Flow of Part Design Information

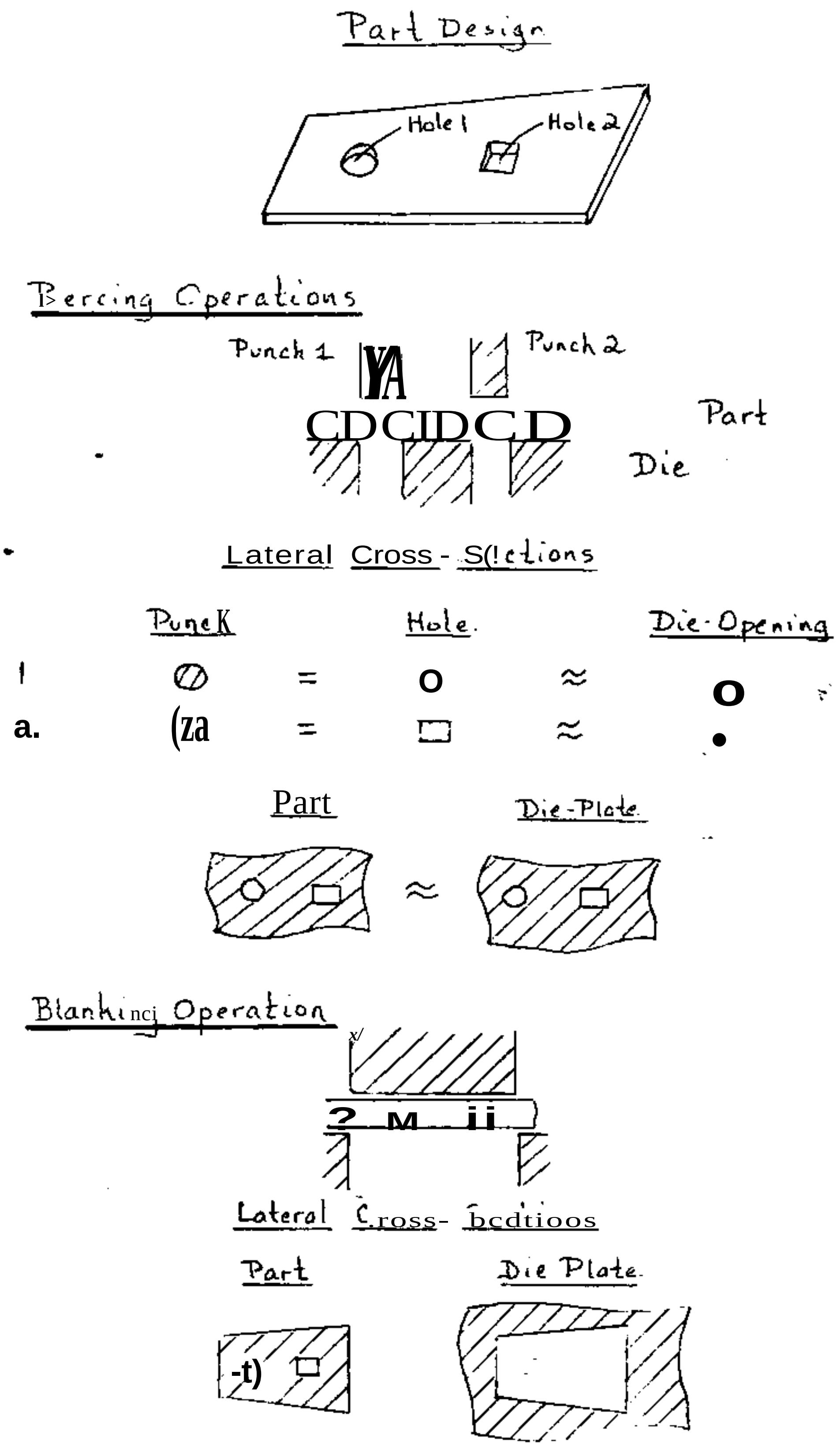

Fig 5 Part to Die/Punch Mapping

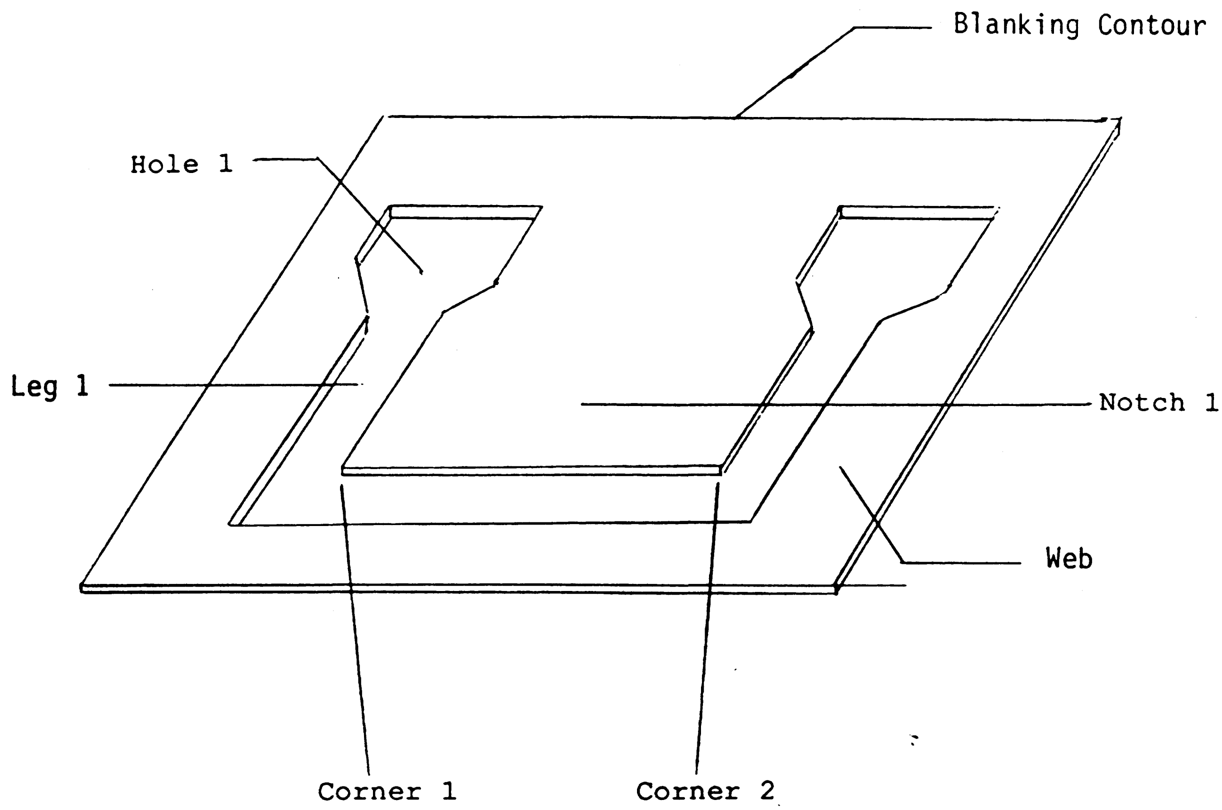

Fig.6 Part of a Lead-Frame

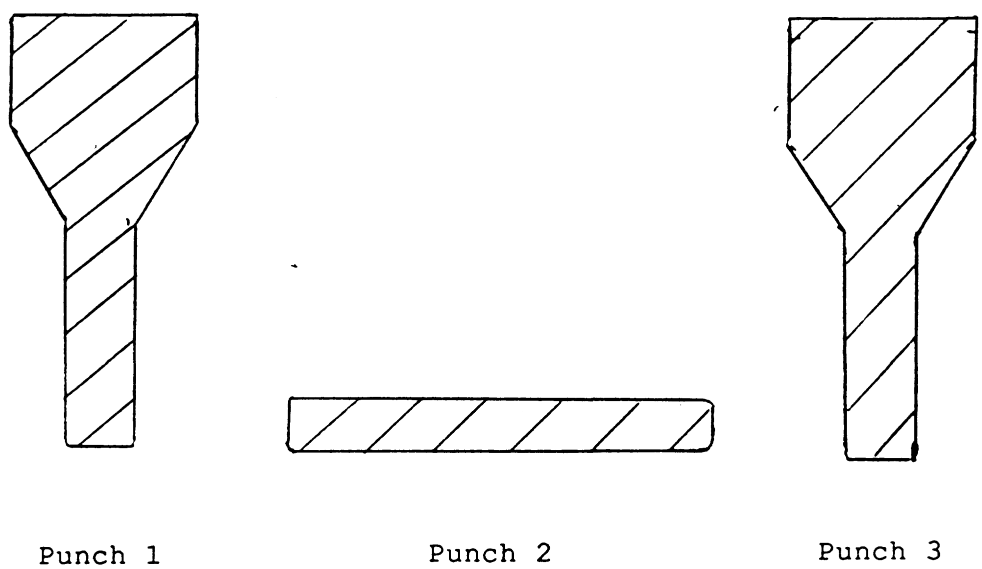

Fig. 7 Cross-Section of Punches to Pierce Hole 1

M.F.	Attribute Value	Effect on P.V.	Effect on I.C.F.	Effect on M.C.F.	Redesign Suggestions
Hole 1	Notch 1: concave	Punch Manuf.: cannot make punch of this x-section		Need at least 2 punches	Get rid of concavity
	Corner 1: radius=0.0	Punch Manuf,: cannot make punch of this x-section		Need at least 2 punches	Set r=0.010"
		Die Stresses: too high	Die Wear: too high	Need at least 2 punches	Set r=0.015"
		Punch Stresses: too high	Punch Wear: too high	Need at least 2 punches	Set r=0.015"
	Corner 2: radius=0.0	(same as Corner 1)			

OUTPUT RESULTS

M.C.F.: Number of Punches

M.F.: Hole 1

M.C.F. Value: 3

Redesign Suggestions:
1) Set Corner 1 radius - 0.015"
2) Set Corner 2 radius - 0.015"
3) Eliminate Notch 1 concavity

Fig.8 Sample Evaluation Procedure for Number of Punches for Hole 1