AD-A 145 628

AD A-145628

TECHNICAL REPORT ARLCB-TR-84027

COMPUTER AIDED PROCESS PLANNING OF MACHINED METAL PARTS

CPT. WALTER W. OLSON

SEPTEMBER 1984

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT CENTER
LARGE CALIBER WEAPON SYSTEMS LABORATORY
BENÉT WEAPONS LABORATORY
WATERVLIET N.Y. 12189

DISCLAIMER

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

The use of trade name(s) and/or manufacture(s) does not constitute an official indorsement or approval.

DISPOSITION

Destroy this report when it is no longer needed. Do not return it to the originator.

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	ARLCB-TR-84027
2. GOVT ACCESSION NO.	
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle)	Computer Aided Process Planning of Machined Metal Parts
5. TYPE OF REPORT & PERIOD COVERED	Final
6. PERFORMING ORG. REPORT NUMBER	
7. AUTHOR(s)	Captain Walter W. Olson
8. CONTRACT OR GRANT NUMBER(s)	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	Armament Research & Dev Center, HQ, U.S. Army, Armament, Munitions and Chemical Command, Benet Weapons Laboratory, Watervliet, NY 12189
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS	AMCMS No. 3297.06.7724 DA Project M1-1-P2613-M1-1A PRON No. 68V7724
11. CONTROLLING OFFICE NAME AND ADDRESS	Armament Research & Dev Center, HQ, US Army, Armament, Munitions and Chemical Command, Dover, NJ 07801
12. REPORT DATE	September 1984
13. NUMBER OF PAGES	26
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	
15. SECURITY CLASS. (of this report)	Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Computer Aided Process Planning
Variance Systems
Generative Systems
Functional Analysis
Expert Systems
Machineability

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Although process planning is more of an art than a science today, its automation is both possible and feasible. Variant computer aided systems exist and can be applied now. These systems should not have a great effect upon organizational structure. Generalized generative process planning does not exist and probably will not in the near future. However, several special purpose generative systems are available in experimental form. The capabilities of these systems must be planned during the design by a judicious choice of approaches and properties to solve the process planning problem.

20. Currently, generative systems should be designed for a specific plant or for specific processes. A generative system, if employed, must be considered in the overall scope of computer integrated manufacturing as it needs data existing in other data bases and it has potential organizational impact.

CONTENTS

INTRODUCTION

Process planning is the art and/or science of converting a completed design of an end product into instructions which describe and control the processes that are required to generate the end product from some raw material. These instructions may take the form of process drawings, numerical controlled tool instructions, process route sheets, tool and/or machine specifications. Computer aided process planning is the use of a computer to assist in producing the documents needed to define the manufacturing process for a given part. The assistance can take the form of aids for numerical computations, word processing, drawing/drafting, data storage and retrieval, machine loading and planning, numerical controlled tool instruction formulation, data transmittal, design and process analysis and route sheet production.

Computer process planning may be broken into three distinct categories based upon the type and capability of the assistance.

Aids such as drafting or word processing, which are general use tools not specifically designed for the process planning task, are incidental systems. Such systems include Wordstar (TM of Micropro International), a general purpose word processing program and ANVIL 4000 (TM of MCS, Inc.), general purpose computer aided drafting system.

Variant computer aided process planning takes a previous process plan and changes it to meet the current need, thereby creating a variation to the original plan. Most variant computer aided process planning systems employ hierarchial data storage and retrieval methods to give the process planner a form of process plan that has either been used before or is considered standard within the facility and can be used as a starting point for planning. Such systems are often coordinated with a group technology coding and classification systems, which helps solve the storage and retrieval problem as well as the analysis problem. These systems sometimes include a machine tool data base, a material data base, or a machineability data base. They always include a process plan data base. A well known commercial system that provides variant capability is Multiplan (TM of OIR, Inc.).

Systems that actually perform the planning function are termed generative. This definition has been abused recently by several vendors, who have increased the capabilities of a variant system to perform some limited aspects of process planning but do not address the total function of converting an engineering design into the complete list of processes and process specifications needed by a manufacturer to faithfully execute the intent of the designer. Such systems might be called semi-generative or advanced variant systems, depending upon system capabilities.

A true generative system uses the information created by a developer, best presented as a graphical data base, supplemented by nongraphical entries such as material, tolerances and special processes, to create an adequate and efficient process plan. To date, only limited categories of parts can be planned by generative process planning. An example of a generative system for rotational parts is the Computer Production Process Planning system developed by United Technologies Research Center under contract to the US Army Missile Command as part of a Manufacturing Methods Technology program.

NON-COMPUTER METHODS

Currently, in most manufacturing facilities, process planning is a manual, labor intensive, semi-white collar, semi-blue collar, task, which requires extensive training and experience in metal working in addition to a large knowledge of the facility that the process planning is executed for. Many manufacturing managers consider the process planning function an art because there are a mind boggling number of factors that must be considered in order to produce a good process plan. Because of the number of variables involved, few, if any, parts have but one precise method by which they can be made in a given machining shop of reputable size. Therefore, several alternative process plans can, and in many situations, do, exist for identical parts. Usually, the best process plan is that which is considered to produce the part for least cost in a time consistent with other end product parts within the machine shop.

In a moderate sized job shop facility which produces metal parts, it is common to have in the manufacturing organization a division called production planning and control that performs many tasks in addition to the process planning task that is being discussed. Within this division are functional branches for process planning, tool design, plant layout, production control and industrial engineering. An additional division within the manufacturing organization that is affected by process planning is quality control. At different plants and locations, these divisions and branches may be combined, separated or have different titles. The tasks performed are common to most organizations.

The manufacturing order, when received, will take two diferent routes depending upon the nature of the part and amount to be made. If the quantity

is extremely large and disruptive to the present factory flow, or if the part is significantly different in process or material than those previously made within the facility, the design package wil first be examined by the industrial engineering staff to determine if the part can be made, if a new plant layout is required and if new processes must be designed. Based upon the plant layout decision and the process addition decision, the order is cycled through plant layout, process planning, production control, quality control, tool design and industrial engineering until the order is planned sufficiently well.
Normally, a project engineer, from industrial engineering, is assigned to the order to coordinate the planning effort. As this situation is not likely in the planning of a factory, it would require special coordination and planning. Therefore, this type of order planning will not be discussed here.

We will assume that the part is similar in nature and quantity to parts already being produced by the plant, as is normally the situation. Therefore, no new plant layout or new process is likely to be needed. The design is thus assigned to a process planner who develops the manufacturing plan for the part. The process planner, after analyzing the design drawings and requirements, will make a rough estimate of what machines are required. He then sketches out what seems to him a suitable flow through the factory. This flow becomes the rough process plan and is then sent to tool design, production control, quality control and industrial engineering. Tool design will determine tooling, jigs and fixturing of the machines chosen for the operation. Production control assures that materials are present and that the part is manufactured according to the order time requirements. Quality control will review both the design and the process plan to determine the gage requirements and quality control steps needed. Industrial engineering will review the draft process flow to insure that it is consistent with current plan manufacturing methods. Normally, the process planner is personally responsible for seeing that the design is transformed into an efficient process plan. Therefore, he will coordinate with all of the above branches to ensure that the process plan is taking its final shape and to resolve potential conflicts before they affect other branches. As a result, the final process plan bears the name of the process planner, but is in fact, a group effort that has been endorsed by all of the concerned branches.

Some of the complicating factors which must be considered in process planning are machine capabilities, machine usage costs, material properties, material costs, facility loading, shop personnel capabilities and plant floor layout. Machine tools are not only varied in functions, such as drilling, turning, shaping and milling, but they also vary within functions by workpiece size and tolerance limitations, work speed ranges, tool holders, work fixturing devices, and type of controls. Machine specifications are not available in any standard reference. Therefore, the planner must rely upon his previous experience as a machinist to know the capabilities of a specific machine. Machine manufacturer documentation is helpful, although it may be misleading, particularly near the limits of the work range and tolerances of a specific tool, because of wear and tear to the machine and the desire by the manufacturer to accentuate the positive to assist marketing.

Machine usage costs and facility loadings are frequently critical. For example, milling a surface may be faster but a shaper may be a better choice because tool costs are less. This is particularly true if the mill is already loaded with other parts. Reversal of the loading situation may require that the mill be specified. Other machine cost factors are maintenance costs and setup times. For example, setup time on a shaper is generally less than that of a mill. The process planner should know which machines are more prone to failure to avoid planning critical jobs across breakdown prone machines. It is important for a process planner to be well versed in both the relative machine costs and parts to be produced in addition to the part being planned.

Material properties and costs, while having probably the most significant effects upon the process choice and specification, are also the easiest factor for the process planner to consider. Extensive tables of material properties are available, produced by the cutting tool industry, material refiners and material research organizations. While some materials do exhibit great variance as a result of chemistry, most materials are relatively constant from a standpoint of machineability. The main choices are the type of tool, the cutting fluid, the speed and feed of the cutting process, and meeting the requirements for tolerance and stiffness. Most of this information is cataloged. However, it should be remembered that these are guidelines which may require some adjustment to fit a given circumstance.

In a machining facility where lot runs are long and part variability over time is small, machine lines are laid out according to process plans. However, if lot runs are not extensive and part variability is great, other considerations locate machine tools on the shop floor. This tends to complicate process planning. Process planners must know where the machines are, in the anticipated uses of the machines to generate an acceptable process plan. Furthermore, the skills of the personnel operating the machines have to be considered. It is not uncommon for manufacturing plants to introduce apprentice machinists in certain areas limited to rough cutting. The process planner must be aware of this policy to avoid overtaxing the capability of personnel to produce tight tolerance or to perform complex machining operation.

For these reasons, process planning has escaped alteration by mathematical analysis, operations research and introduction of computers into manufacturing. Automation of process planning is not easy. Consequently, industrial engineers and manufacturing engineers have generally avoided working on the process planning function. Process planning remains yet today more art than science although the above variables are quantifiable. It is only recently that computerization of the factory has penetrated the arena of the process planner.

VARIANT COMPUTER AIDED PROCESS PLANNING

The basis for variant process planning is that two similar parts have similar manufacturing processes. Therefore, the process plans would be common in many respects. If a planner were to plan one of the parts, and if the process plan of the other part was available, the planner could save considerable effort by simply copying the pertinent common operations and planning only the dissimilar operations. The basic requirements for a variant process planning system are: a data base or file for process plans, a storage and retrieval method, and word processing capability. The file for process plans provides the initial starting point. This starting point may be a standard plan, previously accepted as a model for future plans or an old plan, retrieved from the data base. If an old plan is used, care must be taken to ensure that equipment, tooling and gages reflect current standards. The process plan data base, provided it exists and has a representative process plan, is the least important of the three requirements.

Several researchers have shown that, in most plants, the number of process plans held on file exceeds the number of distinct parts. Some duplication occurs from the desire to have a different process plan for each different situation. However, most duplications are unintentional and clearly wasteful of the planner's time. Four reasons commonly given for this phenomenon are:

1) There are too many process plans on file to efficiently locate and retrieve a particular plan that might fit a new order unless the order is identified with the particular part.

2) The salient characteristics of a part are not identified and referenced by the filing system.

3) There are no plant standards for process plans.

4) Current planners are not aware of the previous effort.

Group technology was proposed as a possible solution.

Group technology is a method that allows the characteristics of a part, machine or process to be analyzed and matched to an identification number. In short, the identification number is a library reference code based on shape, tolerances, dimensions, materials and other factors. There is some overhead involved in the selection of a group technology code, analyzing parts and assigning them code. However, the result is a cure for problem 2 above. Once the parts are codified and the plans organized or location referenced by the coding scheme, problems 1 and 4 can also be resolved. The remaining problem requires additional analysis and standardization, which can not be performed until the group technology code has been obtained.

Variant process planning does not require group technology to be effective. However, considerable searching, retrieval and process plan comparison time can be saved when group technology is in use. If group technology is not employed, then some other retrieval method must be used. Effective retrieval techniques include: keyword searching, material and geometrical characteristic comparison searching, and networking. Retrieval is probably the most important operation to a variant process planning system.

Once the initial plan has been retrieved, a word processing function is used to fill in part specific information and to provide new or updated operations. Features required in word processing include formatting, ability to add and delete items, ability to make changes both in individual words and in orders of complete paragraphs or sentences, searching capability for specific phrases, block copying and printing of the plan. While not critical, several additional features should be provided. Among these are a numerical calculator for arithmetic work, a security system to prevent unauthorized tampering and the ability to reference additional information files such as a file of common tooling or gaging. It is the word processor which will, to a large extent, determine user acceptance or rejection of a variant system. Therefore, it should be "user friendly." Help information should be on line, sufficient capability should be immediately available for execution of the foreground task, and the commands should be easy to use without wasted motion or keystrokes, yet should not allow the user to inadvertently make mistakes.

Several additions might easily be made. One addition is a file for standard machine tool specification and data which might be useful in planning a process. Another might be a machineability data base. Standard costing is frequently required and therefore should be provided. Sketching and drafting of intermediate operations and fixturing is extremely helpful when the operation is complex, the fixturing or jigging somewhat difficult or the operation difficult to describe in words. This capability has been added to some commercial systems and has been well received.

Organizationally, the introduction of variant process planning should have little or no effect. For organizations without a computer system, the use of a variant system will require building a system support organization, not necessarily under the manufacturing operations section. While most variant systems in use today are designed for mainframe or mini computers, the advent of microcomputers with considerable storage capability portends microcomputer based variant process planning. Indeed, such a system using IBM PC XT's (TM of International Business Machines, Inc.) is in the final stages of development at Watervliet Arsenal, New York. It is currently scheduled for initial implementation during the 1st Quarter of FY 1984.

Variant systems currently on the market include Multiplan (TM of OIR, Inc.), CV-Miplan (TM of Computervision), PICAPP (TM of PICAPP, Inc.) and CSD/AML (TM of Rath and Strong System Products, Inc.). Although many commentors regard the following systems as generative, the following two systems could be considered advanced variant systems or semi-generative: D-CLASS (TM of Brigham Young University) and GTCC/GTSS which was developed under US Air Force contract by General Dynamics-Vought.

GENERATIVE PROCESS PLANNING

True generative process planning develops complete process plans and manufacturing routings from the design data. While considerable engineering and development is currently underway in this area, there is no general purpose generative computer aided process planning system for a manufacturer of metal parts. This many change in the near future but probably won't. The difficulty of defining machine tool specifications needed at the application site, the gross differences in design data for a part and the lack of uniform standards for machining will probably prevent the development of a general purpose generative system in the near future.

However, special purpose generative systems for specific plants or a specific type of parts are feasible and have been developed by several organizations. These systems have well defined limitations. The goal of such systems is to address the problems of process planning for single type of parts, and later to generalize the experimental system. Normally, these systems are factory dependent; the knowledge about what machines are available and tooling is in use is well known.

The development of a generative process planning system requires solution of several varied problems. Geometrical representation, manufacturing flow selection, machine specification, tool and fixturing definition, raw material design, time and cost computation and choosing between competing processes are representative of the type of problems that any system designer must address to build a generative process planning system.

Several attempts have been made using group technology to represent part geometry. While this technique is successful in choosing the macro process planning steps (e.g., the choice of machines and a process flow), group technology coding schemes do not carry enough data to design specific operations. Ideally, the geometrical information should be isomorphic to the product. This implies that all design aspects of the final part could be determined from the information given the process planning system. Unfortunately, this is not possible with any graphical format in existence today. Variations in tolerancing, drafting, and inability of a designer to completely specify a part prevent isomorphic representations. At best, a homomorphic representation must be selected. The data used by a generative system will be incomplete, but extraction of data from the design must be complete enough to develop an efficient process plan. Part geometry has to be digitized, either through extraction from a computer aided design data base or by some person entering pertinent information through a computer terminal. (In an expert system described below, the information is entered using a standard nongraphics terminal, in which case the system relies upon the operator for building the geometrical data).

Manufacturing process flow depends upon plant layout and loading forecast when the part under consideration is introduced onto the plant floor. Even the best plans can be delayed by unexpected work stoppages. Such stoppages may be caused by maintenance problems, unanticipated schedule changes, or other events beyond the control of the planner (computer or human). In process planning, flexibility should be afforded the plant floor management. Some operations may require that one and only one machine be used to make a part. However, this should be the exception rather than the rule. Manufacturing flow is greatly simplified if the plant floor consists of machine cells designed around certain parts or if the plant has colonized its machines. Particular care must be given to placement of material handling devices such as conveyors, cranes or robots. Plant layout information must be incorporated into a data base for a generative system in some manner. Typically, the best information would involve using original data furnished by plant layout, production control, and industrial engineering.

The problem of machine specification can only be solved if the capabilities of the machines can be quantified. Relevant information includes spindle capacity, work space dimensions, accuracy, cycle times, location on the plant floor and kind of control units. This problem is closely related to the problem of tooling and fixturing specification, in that neither problem can be totally separated from each other. The two types of information required are principally geometrical work envelopes and cataloged parameters. This information must be combined with geometrical and material information from the part design. For numerical controlled machine tools, several computer aided design systems produce adequate part programming, using either APT Or COMPACT code. This can be and should be incorporated into a generative system.

Raw materials available must be cataloged in a data base which includes the material, cost, quantity available and geometrical information. Forgings, stampings and castings present a special challenge. Ideally, a generative system would suggest the use of such processes. Because of the complexiity in designing forgings, castings and stampings, most generative systems in the near future will be provided the requirement to use the output of such a process from the system operator.

There usually is more than one process to produce a metal part. A generative system must be able to compute alternative process plans, to compare costs, times and compute factory optimization. The almost infinite variety of process plans for a given part prevent a completely optimal solution. A generative system must be equipped with cost and time computing modules to provide the comparison data required. Some type of decision support is needed if the generative system is to provide near optimal plans. The definition of plant optimization and how to achieve it is still an unsolved problem in operations research and industrial engineering. At the current time, an adequate generative system must be able to produce plans at least as efficient as those that a human planner might propose.

The above discussion leads to three possible forms of generative process planning: macro-generative systems, expert systems and analytic functional systems.

The macro-generative systems start from the theory that the most important difficult decisions involved in developing a process plan are those concerning overall plant flow of a part. Once the plant flow has been determined, micro planning can be added, either by using existing process plans in a data base or by additions made by a human process planner. Therefore, such systems normally use group technology in choice of the process flow. After the overall process flow has been determined by analyzing the part code, most required micro programming is added by extracting information from existing process plans and inserting appropriate geometrical values from part geometry. If an appropriate operation does not exist, a human operator is queried. When the plan is completed, it is given to a human operator for modifications, approval or replanning. Alternates are generated in the same manner, at the discretion of the operator. Most of the planning effort can be executed in batch mode, although modules may permit interactive planning with a human operator.

Expert systems assume all planning is executed by satisfying well defined logic rules. For an expert system, the data, with the exception of part information, is formatted into logical decision rules of the form "IF A SITUATION - THEN TAKE ACTION -." These rules have to be programmed by a "knowledge engineer" who is able to convert information given to him by experienced process planners into process rules. The part information may be presented in several different ways: the technical data may be created by a computer aided design package, in which case the need for human interaction is reduced; the data might be sketched by an operator who has access to a graphics terminal and answers specific questions as they are asked; or the information may be totally word oriented, in which case the operator types in answers in response to queries from the expert system.

Expert systems, while very powerful, are limited in the sense that they are difficult to modify. They require a "knowledge engineer" who is responsible for the logic of the system and the order that the logic is applied. It is the ability of this person (or persons) who either makes the system work or fail. A knowledge engineer would require education in the industrial engineering, specifically processes, as well as a computer science background in expert systems. Additionally, a well trained process planner must work with the knowlege engineer to provide factual plant and operation experience.

An example of a hypothetical planning session might be the following:

OPER: Start expert CAPP.

CAPP: What part do you wish to plan?

OPER: Plunger B29153

CAPP: Please describe the part

OPER: The shape is compound cylindrical. The length is 50 +- .0.3. The largest outside dia is 9.5 +- .02. From center axis of end 1, 1.66 +-0.05, at -75 deg 5.18 +- 0.05, at -15 deg 13.0 +- .15, at 90 deg to 4.75 +- 0.10 from center axis, at -90 deg 7.0 +- 0.1, at -90 deg to 0.2 rad 90 deg arc -.2 to 2.985-0.015, 25. +- 0.2, at 90 deg on 6 +- .5 rad to center axis.

CAPP: Are all dimensions inches?

OPER: No, mm.

CAPP: What is the material?

OPER: Corrosion resistant steel per AMS 5621 hardness C50-C52

CAPP: What is the surface finish?

OPER: 6.3 except for end 6 +- .5 rad: 4

CAPP: What is the quantity?

OPER: 25

CAPP: Standard QC?

OPER: Yes

CAPP: Special instructions?

OPER: No

CAPP: Process plan to follow:

Material: Stock No. 9510-00-897-0000 Corros resist steel Class 420 per AMS 5621

15.7 mm diameter x 52mm rough length

SQAP 167930

NOTE: Dimensions are in millimeters

OPER #	OPERATION AND TOOLS	COST AREA	STD HR	SETUP HR
10	Turn Lathe	1050	1.2	6.0

Hold in collet and face end to clean.

Turn to diam 9.5mm +- .2 to 33mm min length

Form end rad 6mm +- .5 on end from turn 9.5mm and maintain 4 finish on radius

Turn 5.97mm - .03 to 25mm +- .2 length with fillet rad .2mm -.2

Part off (50) to 52mm - 1 length

Tools: Tool, From 6 R #12529707 T001C

20	Turn Lathe	1050	.800	3.0

Hold in soft jaws to not mark 5.97 diam

Face 50 +- .3 O.A. length

....

CAPP: Is above plan accepted?

OPER: No. Oper 20: Change soft jaws to collet.

CAPP: Done. More changes?

OPER: No End CAPP

While this example is of a very simple and common part, more complex parts would be handled in much the same way. Note that the operator did not have a graphics data base. If a graphics data base had been present, the process could be made considerably more efficient. Also note that the process plan was reviewed by the operator before being accepted. An expert system should be able to present the logic used in determining process plans. If the plan presented was flawed, the operator then could examine the rules used to arrive at the process plan and bypass a specific rule application or present an error correction requirement to the knowledge engineer.

An example of an expert system for generative process planning is the CPPP system earlier mentioned for rotational parts. This system relies upon rule selection and rule logic for determining process plans from rotational products.

The analytic functional system approach assumes that a metal surface is transformed into a new surface by some machining operation. The transformation is a function or mapping between the original surface and the resulting surface. From the mathematical descriptions of the surfaces, the mapping function can be determined. Tools are considered as capable of producing certain mapping functions, and in some cases, may produce several functions. Process planning is the mathematical analysis of the two surfaces, determination of the mapping function, choosing the tool for that function, followed by choices of machines and routings.

For example, consider a surface described completely by data in a set S. This surface must be machined into a surface which is described completely by the set T. Mathematically, this can be described as:

$$T = f(S)$$

where f is the machining function. This notation implies that one and only one set T can result from a functional mapping of S by f. Explicit data must be available for both T and S to determine f. The function may not exist. T might represent a cylinder of diameter 6 inches and length 10 inches made of SAE 4340 steel. If S is an Aluminum sheet stock, obviously the function f does not exist in this context. However, if S is bar stock of SAE 4340 steel of diameter

7 inches and length 10 feet, a function f could be derived. Such a function might be represented by:

$T = f(S)$

T is bound by the equations

$z_1 = 0$

$z_2 = 10$

$x^2 + y^2 = 36$

$M = 4340$

S is bound by

$z_1 = 0$

$z_2 = 120$

$x^2 + y^2 = 49$

$M = 4340$

A suitable function f might be

$f\ (z_1) = z_1$

$f\ (z_2) = z_2 - n,\ n < z$

$f\ (r_T) = r - p$

$f\ (m) = M$

This function can be compared to a tool function which corresponds to a single pointed HSS turning tool.

$g(z_1) = z_1$

$g\ (z_2) = z_2 - n < z - 2$

$g\ (r_T) - r - p$

$g(m) = M$

Having derived a function f, we can see that this function is in the class of functions that might be serviced by a screw machine.

Analytic functional generative process planning system design involves determining which variables are relevant to process planning, choosing a data structure to capture this information, choosing an analysis technique to develop the correct process planning function and developing the class of functions for each tool available. The mathematical question of which algebras and properties are required must be answered before designing a system. For example, do the two surfaces need to be linked by invertable functions? The answer to this question determines whether or not the proposed generative system has the ability to develop a process plan by starting with given raw material. The mathematical properties of the transformations affect the complexity of the system, the capabilities of the system to perform certain tasks, the precision of process selection and the ability to find alternate selections.

An example of an experimental generative process planning system using the analytic functional approach to process planning was developed by William Lewis and others at Purdue University.

These three methods need not be totally independent of each other. For example, processing time can be reduced if the macro-generative technique is used before either applying rules or analytic functions. Certainly, the development of classes of functions and perhaps the process functions themselves can be assisted by some type of rule logic. It is probable that any useful generative system will combine the above techniques to achieve its end goal: the process plan.

The complicating factors discussed under current manual process planning have to be addressed in a generative system. Most of the information needed exists in other data bases of the integrated factory. Particular information needed by the generative system includes developmental design, scheduling, plant layout and inventory. It is doubtful that a true generative process planning system could achieve maximum efficiency without an interface to a material resource planning system or similar purpose system. Some of the information that is taken for granted in the experience and knowledge of a human process planner exists in digital form only in the MRP system. Therefore, a generative process planning system must be designed as part of the integrated factory rather than as a separate independent project.

Whereas the variant system had little structural effect upon the manufacturing organization, a capable generative system has considerable potential for disruption. First, a generative system, if it is efficiently producing process plans in the manner in which it was designed, means that process planners will be replaced, although not totally.

Second, the generative process planning takes on more responsibility than is normally vested in the process planning section. Areas affected are tool design, quality control, industrial engineering and production control. Before a generative system, elements were added to the process plan by all of these sections. After generative planning, much of this work should either be eliminated or reduced. As generative process planning is part of the automated factory of the future (with a future,) its impact on the organization should be considered.

CONCLUSION

Although process planning is more of an art than a science today, its automation is both possible and feasible. Variant computer aided systems exist and can be applied now. These systems should not have a great effect upon oranizational structure. Generalized generative process planning does not exist and probably will not in the near future. However, several special purpose generative systems are available in experimental form. The capabilities of these systems must be planned during the design by a judicious choice of approaches and properties to solve the process planning problem. Currently, generative systems should be designed for a specific plant or for specific processes. A generative system, if employed, must be considered in the overall scope of computer integrated manufacturing as it needs data existing in other data bases and it has potential organizational impact.

REFERENCES

Allen, Dell K., Generative Process Planning using DCLASS Information System, Monograph No. 14, February, 1979, Brigham Young University, Provo, Utah.

Barash, M. M., and P.B. Berra, Automated Planning of Optimal Metal-Cutting Operations and Its Effect on Machine Tool Design, Journal of Engineering for Industry, ASME, May 1971.

Barash, M. M., E. Barlett, I. Finfter, and W. C. Lewis, Process Planning Automation -- A Recursive Approach, NSF Grant No. APR74 15256, Report No. 17, Purdue University, West Lafayette, Indiana, December 1980.

Bjorke, O., Design for Production, Trondheim, Norway, 1978.

Boothroyd, G., and P. Rusek, Maximum Rate of Profit Criteria in Machining, Journal of Engineering for Industry, ASME, February, 1976.

CAM-I Training Material for CAPP CAM-I Automated Process Planning, Volumes I and II, TM-78-AMP-01, Arlington, Texas, 1978.

Dargie, P.P., K. Parmeshwar, and W. R. D. Wilson, MAPS-1: Computer Aided Design System for Preliminary Material and Manufacturing Process Selection, Journal of Mechanical Design, ASME, January 1982.

Emerson, Charles, Vincent Bond and Inyong Ham, Automated Coding and Process Selection, 1981 Manufacturing Engineering Transactions, 9th North American Manufacturing Research Conference, 1981.

Ermer, D. S., Optimization for Constrained Machining Economics Problem by Geometric Programming, Journal of Engineering for Industry, November 1971.

Field, M., N. Zlatin, R. Williams, and M. Kronenberg, Computerized Determination and Analysis of Cost and Production Rates for Machining Operations, Journal of Engineering for Industry, August 1969.

Gevarter, William B., Expert Systems: Limited but Powerful, Spectrum, IEEE, August, 1983.

Glorioso, Robert M., and Fernando C. Colon Osorio, Engineering Intelligent Systems, Digital Press, Bedford, MA, 1980.

Groover, Mikell, Fundamental Operations, Spectrum, IEEE, May 1983.

Halevi, Gideon, and Roland Weill, Development of Optimum Process Planning Procedures, Technion, Haifa, 1981.

Halevi, Gideon, The Role of Computers in Manufacturing Processes, John Wiley and Sons, 1981.

Ham, Inyond, Advanced Applications of Group Technology Concept for Effective CIM Implementation, MS82-245, Society of Manufacturing Engineers, May, 1982.

Hati, S. K., and S. S. Rao, Determination of Optimum Machining Conditions -- Deterministic and Probabilistic Approaches, Journal of Engineering for Industry, ASME, February 1976.

Hitomi, K., Optimization of Multistage Machining System: Analysis of Optimal Machining Conditions for the Flow Type Machining System, Journal of Engineering for Industry, ASME, May 1971.

Hitomi, K., Manufacturing Systems Engineering, Taylor and Francis, Ltd., London, 1979.

Hitomi, K. and I. Ham, Group Scheduling Technique for Multiproduct, Multistage Manufacturing Systems, Journal of Engineering for Industry, ASME, August 1977.

Hitomi, K. and I. Ham, Product Mix and Machine Loading Analysis of Multistage Production Systems for Group Technology, Journal of Engineering for Industry, ASME, June, 1982.

Houtzeel, Alexander, Classification and Coding, TNO, Organization for Industrial Reseach, Waltham, MA.

Ito, Yoshimi and Hidenori Shinno, Structural Description and Similarity Evaluation of the Structural Configuration in Machine Tools, Int. J. Mach. Tool Des. Res., 1982.

Kahino, Ohba, Moriwaki and Iwata, a new Method of Parts Descritpion for Computer Aided Production Planning, Trondheim, Norway, 1981.

Kops, L., Economical Aspects of Cutting Speed Selection when Turning Stepped Parts, Journal of Engineering for Industry, ASME, November 1971.

Kotler, Richard A., Computer Aided Process Planning, US Army ManTech Journal, November 1979 and January 1980.

Kutcher, Mike, Automating it All, Spectrum, IEEE, May 1983.

Lewis, William C., Elizabeth Bartlet, Israel I. Finfter and Moshe M. Barash, Tool Oriented Automatic Process Planning.

Lewis, William C., Moshe M. Barash and James J. Solberg, Data Flow of an Automated Job Shop: Are Dynamic Allocation and Scheduling Comparably Effective?, Proceedings of the American Control Conference, June 182.

Niebel, Benjamin W., An Analystical Technique for the Selection of Manufacturing Operations, The Journal of Industrial Engineering, November 1966.

Nof, Shimon Y., and Moshe M. Barash, Dynamic Process Selection Procedures and Their Effect on Machine Configuration, Int. J. Tool Des. Res. Vol 20, 1980.

Rao, S. S. and S. K., Computerized Selection of Optimum Machining Conditions for a Job Requiring Multiple Operations, Journal of Engineering for Industry, August, 1978.

Schaffer, George, GT via Automated Process Planning, American Machinist, May 1980.

Suh, N. P., A. C. Bell and D. C. Gossard, On an Axiomatic Approach to Manufacturing and Manufacturing Systems, Journal of Engineering for Industry, May 1978.

Vogel, S. A., Interfacing Computer Aided Process Planning with CAD/CAM, Conference on Computer Aided Manufacturing and Productivity, London, October, 1981.

TECHNICAL REPORT INTERNAL DISTRIBUTION LIST

	NO. OF COPIES
CHIEF, DEVELOPMENT ENGINEERING BRANCH	
ATTN: SMCAR-LCB-D	1
-DA	1
-DP	1
-DR	1
-DS (SYSTEMS)	1
-DS (ICAS GROUP)	1
-DC	1
CHIEF, ENGINEERING SUPPORT BRANCH	
ATTN: SMCAR-LCB-S	1
-SE	1
CHIEF, RESEARCH BRANCH	
ATTN: SMCAR-LCB-R	2
-R (ELLEN FOGARTY)	1
-RA	1
-RM	2
-RP	1
-RT	1
TECHNICAL LIBRARY	5
ATTN: SMCAR-LCB-TL	
TECHNICAL PUBLICATIONS & EDITING UNIT	2
ATTN: SMCAR-LCB-TL	
DIRECTOR, OPERATIONS DIRECTORATE	1
DIRECTOR, PROCUREMENT DIRECTORATE	1
DIRECTOR, PRODUCT ASSURANCE DIRECTORATE	1

NOTE: PLEASE NOTIFY DIRECTOR, BENET WEAPONS LABORATORY, ATTN: SMCAR-LCB-TL, OF ANY ADDRESS CHANGES.

TECHNICAL REPORT EXTERNAL DISTRIBUTION LIST

	NO. OF COPIES
ASST SEC OF THE ARMY RESEARCH & DEVELOPMENT ATTN: DEP FOR SCI & TECH THE PENTAGON WASHINGTON, D.C. 20315	1
COMMANDER DEFENSE TECHNICAL INFO CENTER ATTN: DTIC-DDA CAMERON STATION ALEXANDRIA, VA 22314	12
COMMANDER US ARMY MAT DEV & READ COMD ATTN: DRCDE-SG 5001 EISENHOWER AVE ALEXANDRIA, VA 22333	1
COMMANDER ARMAMENT RES & DEV CTR US ARMY AMCCOM ATTN: SMCAR-LC	1
SMCAR-LCE	1
SMCAR-LCM (BLDG 321)	1
SMCAR-LCS	1
SMCAR-LCU	1
SMCAR-LCW	1
SMCAR-SCM-O (PLASTICS TECH EVAL CTR, BLDG. 351N)	1
SMCAR-TSS (STINFO) DOVER, NJ 07801	2
DIRECTOR BALLISTICS RESEARCH LABORATORY ATTN: AMXBR-TSB-S (STINFO) ABERDEEN PROVING GROUND, MD 21005	1
MATERIEL SYSTEMS ANALYSIS ACTV ATTN: DRXSY-MP ABERDEEN PROVING GROUND, MD 21005	1
COMMANDER US ARMY AMCCOM ATTN: SMCAR-ESP-L ROCK ISLAND, IL 61299	1
COMMANDER ROCK ISLAND ARSENAL ATTN: SMCRI-ENM (MAT SCI DIV) ROCK ISLAND, IL 61299	1
DIRECTOR US ARMY INDUSTRIAL BASE ENG ACTV ATTN: DRXIB-M ROCK ISLAND, IL 61299	1
COMMANDER US ARMY TANK-AUTMV R&D COMD ATTN: TECH LIB - DRSTA-TSL WARREN, MI 48090	1
COMMANDER US ARMY TANK-AUTMV COMD ATTN: DRSTA-RC WARREN, MI 48090	1
COMMANDER US MILITARY ACADEMY ATTN: CHMN, MECH ENGR DEPT WEST POINT, NY 10996	1
US ARMY MISSILE COMD REDSTONE SCIENTIFIC INFO CTR ATTN: DOCUMENTS SECT, BLDG. 4484 REDSTONE ARSENAL, AL 35898	2
COMMANDER US ARMY FGN SCIENCE & TECH CTR ATTN: DRXST-SD 220 7TH STREET, N.E. CHARLOTTESVILLE, VA 22901	1

NOTE: PLEASE NOTIFY COMMANDER, ARMAMENT RESEARCH AND DEVELOPMENT CENTER, US ARMY AMCCOM, ATTN: BENET WEAPONS LABORATORY, SMCAR-LCB-TL, WATERVLIET, NY 12189, OF ANY ADDRESS CHANGES.

TECHNICAL REPORT EXTERNAL DISTRIBUTION LIST (CONT'D)

	NO. OF COPIES
COMMANDER US ARMY MATERIALS & MECHANICS RESEARCH CENTER ATTN: TECH LIB - DRXMR-PL WATERTOWN, MA 01272	2
COMMANDER US ARMY RESEARCH OFFICE ATTN: CHIEF, IPO P.O. BOX 12211 RESEARCH TRIANGLE PARK, NC 27709	1
COMMANDER US ARMY HARRY DIAMOND LAB ATTN: TECH LIB 2800 POWDER MILL ROAD ADELPHIA, MD 20783	1
COMMANDER NAVAL SURFACE WEAPONS CTR ATTN: TECHNICAL LIBRARY CODE X212 DAHLGREN, VA 22448	1

	NO. OF COPIES
DIRECTOR US NAVAL RESEARCH LAB ATTN: DIR, MECH DIV CODE 26-27, (DOC LIB) WASHINGTON, D.C. 20375	1 1
COMMANDER AIR FORCE ARMAMENT LABORATORY ATTN: AFATL/DLJ AFATL/DLJG EGLIN AFB, FL 32542	1 1
METALS & CERAMICS INFO CTR BATTELLE COLUMBUS LAB 505 KING AVENUE COLUMBUS, OH 43201	1

NOTE: PLEASE NOTIFY COMMANDER, ARMAMENT RESEARCH AND DEVELOPMENT CENTER, US ARMY AMCCOM, ATTN: BENET WEAPONS LABORATORY, SMCAR-LCB-TL, WATERVLIET, NY 12189, OF ANY ADDRESS CHANGES.