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Research Paper

MANUFACTURING FLEXIBILITY THROUGH COMPUTER-AIDED PROCESS PLANNING AND CELL SELECTION

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This paper presents an approach to developing a computer-aided process planning in which three important areas of production systems are integrated. The system takes advantage of the relationship among group technology, process planning and scheduling to develop a parts processing system that considers overlapping processing of parts in more than a single cell. The system uses the powerful feature of object-oriented paradigm to develop object coding of parts that focuses on the relationship between parent and children and the inheritance feature of the object-oriented paradigm.

Keywords: Computer-Aided Alternative Process Planning, Group Technology, Scheduling, Object-oriented

INTRODUCTION

In assembling birthday presents for the kids, one sometimes wishes for a third hand and the wisdom to know when and where to apply it. Industry too finds itself wishing for the third, fourth, and fifth hands. As brain struggles to compete in the global marketplace, where more than ever before, the competitiveness of a manufacturing industry with batch production is being measured by its effective utilization of manufacturing resources and prompt responsiveness to technological changes (Dynamicity).

It is becoming increasingly difficult to disregard the interdependencies among Process Planning (PP), Group Technology (GT), and Scheduling. Machine cells and part families in GT are only as

good or as efficient as the Process Plan upon which its development is based; so also is the scheduling system that emerges from the process. This article is about one of those “extra hands”, Computer-Aided Alternative Process Planning (CAAPP). First, however, the literature review demonstrates the nature of process planning and its related partners, GT and Scheduling.

BACKGROUND

Process Planning

Process planning has been used or developed to present different aspects of the manufacturing system. Hernan *et al.* (2003) use the same concept for a multiobjective under uncertainty.

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This could be construed as a situation where the process planner does not know what is available on the shop floor and hence decides to develop several alternatives. However, this is not the case for these authors as their approach is designed to address investment planning. A part or product to be manufactured is usually presented in the form of an engineering drawing. This drawing must be interpreted in terms of the manufacturing processes and procedures, a process referred to as PP, which is the systematic determination of the methods by which a product is to be manufactured economically, efficiently and competitively. It is further defined as the area of Computer Aided Manufacturing (CAM) that is concerned with the sequence of production required to make a part. While Numerical Control (NC) is concerned with controlling the operation of a single machine, process planning considers the sequence-of-operation steps needed to make a part from start to finish usually employing successive operations on several machines. PP must consider both the state of the workpiece at each workstation as well as the physical routing of the part along the shop floor.

Sometimes, flow diagrams and other information such as specifications, tooling requirements, and machining conditions can be used to develop the production sequence for fabricating a part in the fastest, most economical way. Recently, especially in low volume manufacturing systems, the computer has become an important part of the activity, the result of which is Computer Automated Process Planning (CAPP). While process planning systems commonly use a retrieval technique based on part shape families and standard types of tooling and fabrication, CAPP systems often group parts in families based on common fabrication methods.

A process plan for a given product provides specifications for the manufacturing process in detail, giving the proper sequence of operations and the facilities required to complete these operations. The process plan plays a crucial role in linking design and manufacturing functions and an established part of manufacturing of which GT is an important part. While PP still offers several advantages such as minimizing cost and increasing productivity, standardizing it has become a problem because the manufacturing logic for making a product may be applied differently by different process planners. However, this has not changed its fundamental philosophy. In recent years, Computer-Aided Manufacturing (CAM) software seems to be getting us closer to standardization as parts' fabrication complexity are being reduced.

Group Technology

Group Technology, for the purpose of design and manufacturing efficiencies, seeks to arrange separate machine groups with appropriate internal layout. The production of specific component families is formed according to either the similarity of their features or the operations performed by them. This ends in groups of machines referred to as machine cell processing groups and groups of parts referred to as part families.

Parts are identified in GT by using an alphanumeric code that records the various used characteristics such as size, shape, material, tolerance and manufacturing process. The GT system commonly used includes:

- Hierarchical codes; whereby each successive digit identifies special sub-categories using a hierarchical tree arrangement.
- Polycode or attribute code; wherein each

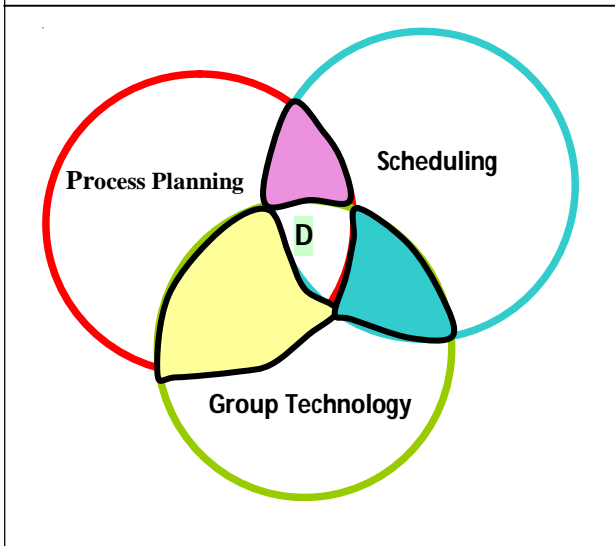
independent digit is assigned a piece of information.

- A mixed coding system; wherein hierarchical and attribute coding systems are combined. It uses part codes composed of hierarchical codes within attributes.

One of the advantages of GT is that it allows the efficiency of flow production organization to be obtained in what otherwise would be jobbing or batch manufacturing. Because of the similarities in workparts, GT promotes standardization of several areas of manufacturing thereby eliminating problems with tooling and setups since drastic changeovers in setup are not required. Through this standardization, the cost of process planning function can be reduced as a new part (with known codes) can be easily identified as belonging to a certain family whose codes are already in the system.

planning function. A well designed scheduling system is able to maximize production throughput and also increase efficiency and quality. In view of the given definitions of GT, PP, and Scheduling, it is easy to note the interdependencies that exist between and among them. In spite of the recognition given to these interdependencies among them, the development of each area has progressed independently in most cases. However, Smith *et al.* (1992) explored a similar process planning and construct a CAPP with elliptical shape (non-axisymmetric) shape. They combine three modules that include three-dimensional modeling that calculates surface area, blank design that creates an oval-shape with identical surface area and the process planning model based on production rules that are generated and upgraded with expert opinions. Figure 1 illustrates the basic relationship between the three functions in an integrated system. At the intersection of Process Planning, Group Technology, and Scheduling is the management decision Variable D, where any conflict between any pair or among the three can be resolved by the management. King and Park (2002) explored a process planning module based on production rules that play the best important roles in an expert system for manufacturing. The production rules are generated and upgraded by interviewing field engineers. Using features to model a part has been thought to be a key factor for the integrated design and manufacturing. Hence, Celic and Unuvar (2013) used object-based modeling to develop a coding method for prismatic parts to be produced and the use of this method in process planning features are structured systematically. To enhance manufacturing flexibility when one of the objectives is searching for the means of effective production processes with economic results Monka and Monkova (2012)

Figure 1: Interrelationship Among The Three Major Functions Of A Manufacturing System



SCHEDULING

Scheduling is the allocation of products to resources (machines, etc.) over time to perform the collection of operations defined in the process

developed software that generated internal mathematical structure and suggested a new code system.

Problem Statement and Goal of Computer-Aided Alternate Process Planning (CAAPP)

Based on a recent review of literature, it is apparent that most manufacturing researchers believe that manufacturing firms usually have an expert process planner within reach or have decided to ignore the relationship that exists between and among PP, GT, and Scheduling. Consequently, manufacturing firms perceive little need to recognize the interrelationship between the PP and the rest of the manufacturing functions or make the PP any simpler than it already is. Many believe that the simpler a PP is, the better it is for all users (Smith *et al.*, 1992). Process planning can be considered in several process models; hierarchical structural, genetic, macro, detailed, and micro. At the setpoint of preliminary design comes the preliminary process planning, which is the process of early manufacturability assessment (Feng and Song, 2000a); as asserted by Feng and Song (2000b). Rodera *et al.* (2002) considered selection of manufacturing resources. Their model of chemical industries has earlier proved NP-hard by Ahmed and Sahinidis (2013). Developing any PP software, on the assumption of the availability of a process planner, may be both unnecessarily time consuming and unlikely for economical reasons. In summary, the problem is that manufacturing needs CAAPP programming to facilitate dynamicity, but it is unlikely that one or smaller companies can find the capital to fund such a project. The goal of this project therefore is to develop a CAAPP module that not only addresses a process plan for a product but also select cells that optimize the production of such part.

METHODOLOGY

The quest for completely automated process planning systems has exposed the lack of techniques capable of automatically understanding the stored CAD models in a manner suitable for process planning. Most current generations of process planning systems have used the ability of humans to translate the part drawing requirements into a form suitable for computer aided process planning, Joshi and Chang (1990). In this study, the approach considers the interdependency between each pair of these manufacturing functions while taking advantage of the common bonds among the functions. Given recognition of these interdependencies, we develop a computer-aided model for selecting an alternate process plan for each product in the system. This model was such that it recognizes the existence and nonexistence of a basic process plan. When a basic process plan does exist, and the process plan is on the assumption that this that the planner has an inadequate knowledge of the structure of the cells, that is, the only knowledge that exists within the system is that the machines are capable of producing parts. It does not assume the parts' existence, physical locations, and or setup in the system. The premise of the model is to use similarity of operations, features and resources to select a cell or combination of cells where a product can be economically completed, and efficiently based on the generated alternate process plan. The model considers first the development of a process plan using all the necessary design features of the part, and then identifies machines capable of accomplishing the defined operations of each part.

The primary objective of the model is the generation of a computerized alternate process

plan and the selection of a single cell where all the operations of a given batch of product can be completed without the need to transfer it to another cell. However, recognizing that this may not always be possible, a combination of cells may also be selected for each product regardless of their status. Having a combination of cells ready for any given product will further increase the flexibility of the system in time of such uncontrollable interruptions as machine failure. This objective is achieved by considering the similarity and geometric attributes of operations of each part type, the capabilities, the efficiency and other attributes such as cost, size, speed, etc., of each machine in selecting either a single cell or combination of cells for a given part type.

As stated earlier, PP establishes the basic processes and procedures to be used to convert raw material into a consumer product. A CAAPP provides the flexibility that enhances the maximization of the system objectives by stating alternate means or routes of manufacturing the same product with the same manufacturing resources. CAAPP provides more than one process, machine, or sequence of manufacturing the same product, thereby increasing the flexibility, efficiency and throughput of the manufacturing system. It also helps to minimize the makespan of the product been manufactured. For example, an operation on a part that otherwise would have been put on hold due to unavailability of resource or machine failure can be easily produced by an alternative process on the same machine or redirected to an alternate machine that has been selected during CAAPP.

While other existing CAPP system deals with just generating a process plan, CAAPP in this context deals with developing the plan and at the same time selecting cells for the processing of

each product based on the constraint of parts, capabilities, and characteristics of the machine cells. CAAPP can either be developed from a variant PP or from an initial technical drawing using the characteristics of all resources.

FEATURES OF THE CAAPP MODULE

The model developed considers both the existence and nonexistence of a basic static variant process plan for each part type, and initial machine cells from which to select the alternatives. With this capability, the end user can specify which of the two models to use for a particular situation. The variant process plan, when known, does not reference machine cells but only the needed processing machines. In this case there is a chance that all machines for a particular or a family of parts will not be in the same cell. The CAAPP module has been developed to first check each operation for the existence of an alternate process. When such is found, the system then proceed to identifying each operation, and then performing a search for processing machines in a chosen cell. Finally, it derives compatibility between the operation and the capabilities of the machines within the cell. Whenever there is a tie between or among machines of the same cell, ties are broken by further considering such criteria as the size, the cost and tooling of each machine. All machines of the same cell selected for a part are referred to as primary machines for that part. The two most important pieces of information utilized by this CAAPP module are the part identification (PartId) and machine identification (MachineId) with all their characteristics. Each part data (according to specifications) includes the required shape, dimension, tolerance, and surface finish

while each machine data include capabilities, size, costs, efficiency, age, and speed.

Each operation is alphanumerically coded, the first letter in the alpha code is a character designating a letter in the operation’s name, and the second letter refers to the standard required for the finished operation based on geometrical tolerances. Machine Identification is an identification number for a given machine. The first letter in the alpha code refers to a letter in the

name of the machine, the second letter specifies a general accuracy of the machine while the number (third in the code) refers to the size of the machine. Tables 1a-1c depict examples of codes used for selected operations of a part in the process.

Each operation also has some characteristics such as tolerance and surface finish and these are represented with the codes shown in Table 1b and 1c.

Table 1a: Code representation for operation					
	Machine (L)	Possible values of digit			
Digit	Feature	1	2	3	4
1	Internal shape (I)	Hole	Groove	Plane	Thread
2	External shape(E)	Contour	Groove	Plane	Thread

Table 1b: Code Representation of Tolerance			
Digit		1	2
Feature		Internal	External
Possible values of code	Tight(T)	<.0001	<.0001
	Superior(S)	.0001-.001	.0001-.001
	Close(C)	.001-.0025	.001-.002
	Medium(M)	.0025-.004	.002-.004
	Loose(L)	0.5-.010	.004-.010

Table 1c: Code Representation for surface finish			
Digit		1	2
Feature		Internal	External
Possible values of code	High (h)	<.25μ	<.25μ
	Medium(m)	(25- 50)μ	(25- 50)μ
	Low(l)	(50- 100)μ	(50- 100)μ
	Neutral(n)	(100- 250)μ	(100- 250)μ
	Loose(L)	0.5-.010	.004-.010

For example, an operation that has a code of I3Sm means that the operation is an internal operation that is plane with a tolerance that is between 0.0001 and 0.001 and the surface finish is between 25 and 50 micron.

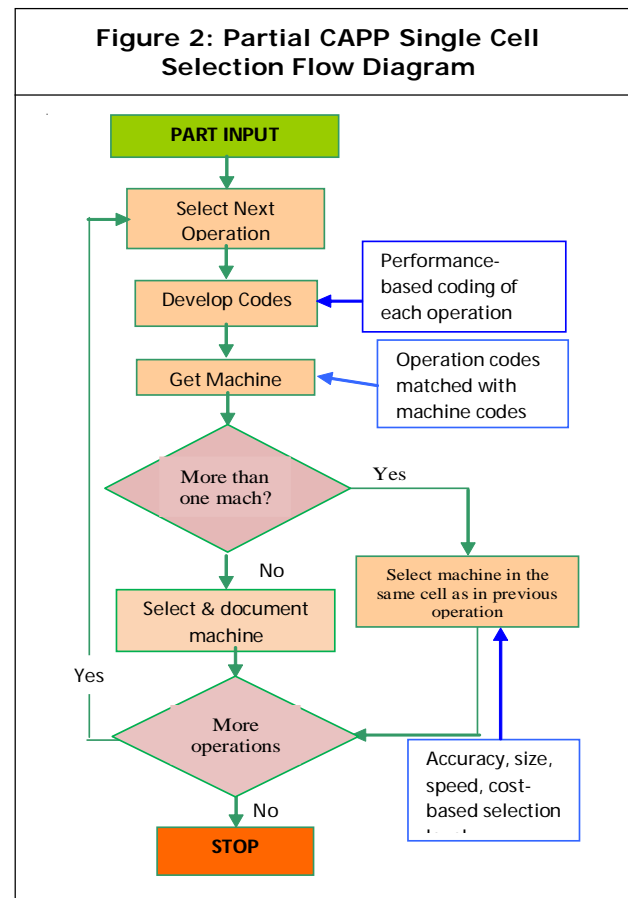
Likewise, in the machine cells, each machine within the cell is described by a character that represents a letter in the name of the machine, another character that presents the overall efficiency of the machine, and a list of codes that defines the capabilities of the machine (i.e., a list of operations that the machine can perform with specified accuracies). The efficiency and accuracy are expressed the same as in operation except that for the machine, the designations are associated with each capability rather than on the machine in general. For example, a Machineld that reveals "LI2Cm" refers to a lathe machine that when used for an internal groove will produce a close tolerance of between 0.001 and 0.0025, and a medium surface finish of between 25 and 50 micro-inches. These elements may change if the same machine were used for threading. In the selection of an alternate machine for any operation, the tolerance code shown for an operation is matched with an equal or higher tolerance code on the machines. When one is found, the corresponding machine is selected for the operation. If more than one is found, the machine with the higher efficiency is selected. However, the machine with the lower efficiency but also suitable for the operation can be reserved for the combination of cells selection.

Selecting a Single Cell

Selecting a single cell means the selection of a cell within which all operations for a part can be completed without having to transport the part to another cell or cells. The most important

information required from the process plan and the machine cell tables respectively are the operationId and Machineld, and the Machineld and capabilities. The procedure for selecting a single cell whose flow diagram appears in Figure 2 is as follows:

From the process plan, the operation identification (OpnId) is retrieved. From this retrieval, the operation alpha code is obtained and then transferred to the first machine-table to check for a compatible machine. This is obtained when the first letter of any of its capabilities matches the first letter in the operation alpha code and whose second letter is higher than or equal to the second letter of the alpha code of the operation. When this information is found, it is saved in a database under the PartId. The



procedure continues until one or more cells are selected for which the criteria for single cell selection and manufacturing are satisfied.

Selecting Combination of Cells

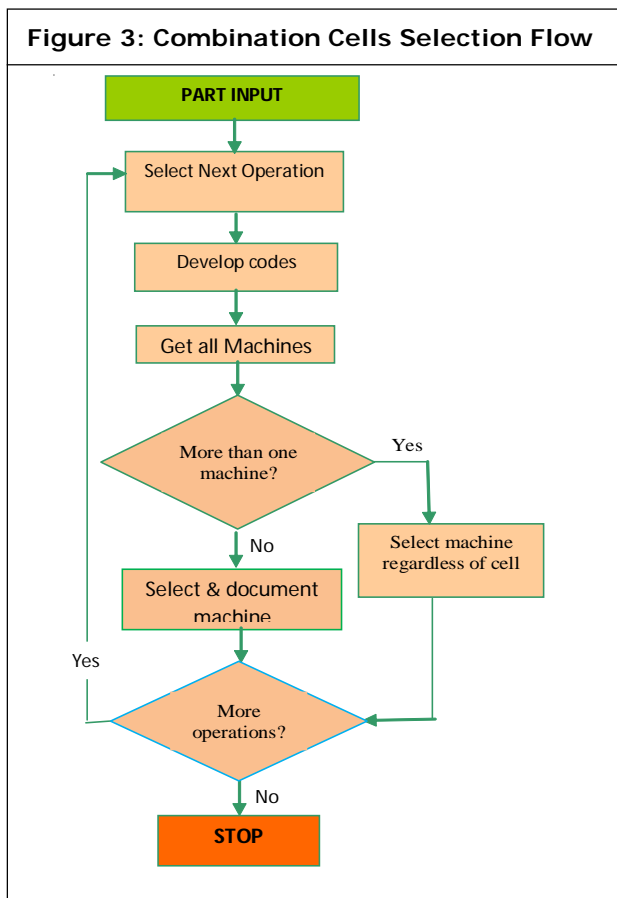
The operations of a shop floor flow are dynamic processes where changes (such as breakdowns) occur without notice. These changes may require the manufacturing of a part to move from one machine or cell to another. Manufacturing of a part within a single cell may be impossible due to the constraints attached to either the operations or the machine cells. The selection of a combination of cells as an alternative for a part better prepares the system for any drastic changes and further increases the flexibility of the manufacturing process. Selection of a combination of cells for a part within a cellular

manufacturing environment is not without some constraints such as the physical distance between cells, availability of resources (Transporters), adequacy of processing tools, etc. These variables are not considered in this model. However, raw material needs and processing tool resources are heuristically considered under other developed modules.

To select a combination of cells whose flow chart is shown in Figure 3, the same procedure is used as for selecting a single cell except that, any machine that has already been selected for the same operation in the single cell processing cannot be considered for that same operation when considering a combination of cells. A machine selected in this process must satisfy all the constraints set forth by part specifications as the primary machine. The objective is to select a combination of cells whose performance minimizes the total number of setups and setup time, and also to avoid cyclic or backtrack processing. Tool availability is another problem that is not taken lightly, therefore, tools are assigned so that duplication and conflict are avoided.

The Object-Oriented Process Planning Paradigm

The object-oriented approach is motivated by the growing interest in object-oriented design, programming and implementation, and the unlimited advantages of its application to manufacturing systems, Bruce (2002). These advantages are especially important when considering the number of functions that take place in planning and the overlap that occurs between and among these functions. For quite a while CAPP remains incomplete and fails to a full implementation of the process planning



activities but with an object-oriented paradigm approach, a system could arise to aid the flexibility of manufacturing a part.

The object-oriented approach provides tools for reducing the complexities that may be associated with CAPP and the traditional approach to designing a process plan. This reduction is in part due to the following strength of the object-oriented paradigm, Demeyer *et al.* (2003):

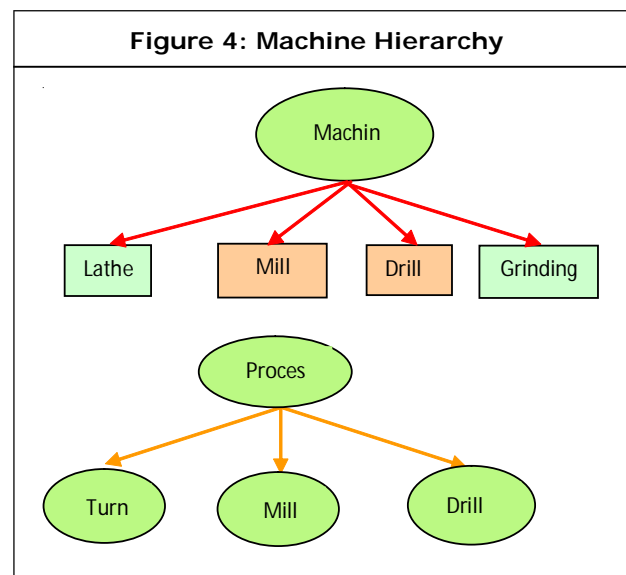
- i. Abstraction, which provides information hiding and complexity isolation capabilities, and
- ii. Inheritance, which enhances reusability, code sharing, consistence of interface, and rapid prototyping, etc.

Recently, Celic and Unuvar (2013) provided an object-coded system based on integrated design and manufacturing where the features that build the part are modeled as manufacturing features.

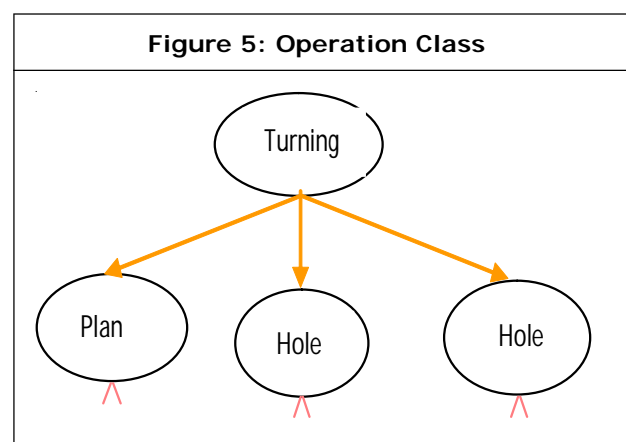
Adding to these strength is dynamic biding, a run time tool that enhances compilation without having to recompile all of its classes, and the ability to alter the internal working of a module within the system without interrupting the activities of the other modules.

In defining objects, each machine hierarchically is a subclass of Machine Object as shown in Figure 4. Each machine is further described by the process attributes, with which process capabilities are in turn attached. Whenever there is a tie between or among machines, variables such as size and cost of each machine help in breaking the ties. These variables are required as input by the user on the first time of use, stored permanently for each machine and are accessed only when required

to break ties. That is, they are not part of regular decision-making elements. While part objects are considered dynamic to an extent, due to use and age related deterioration, all machines objects are considered static for a certain period, and are therefore designed to be revisited to update all necessary attributes as needed. Because the system is designed and implemented using object-oriented paradigm, it is very easy to keep adding and deleting objects and variables as needed.



In a similar fashion, each operation is a subclass of process, and associated with each operation is all of the attributes that enhance the

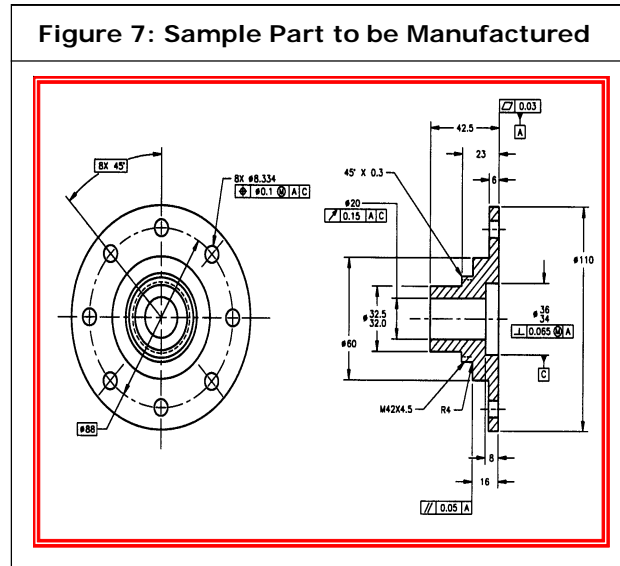
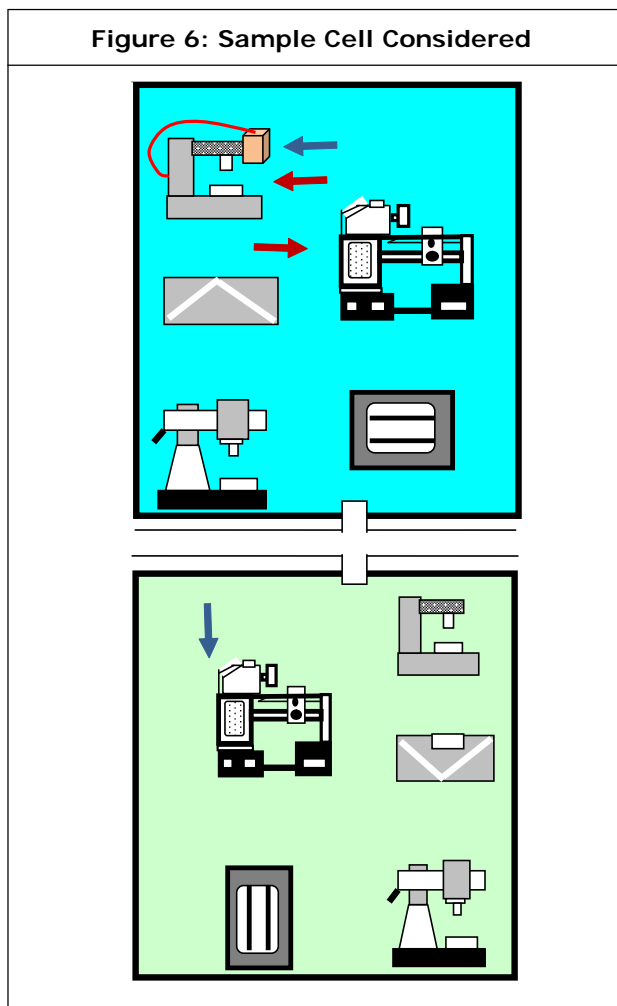


selection of a machine or combination of machines for processing. Figure 5 is a partial illustration of operation hierarchy. Each operation is further described by such attributes as geometrical dimension and tolerance, surface finish and accuracy.

System Testing

The system was tested using a pseudo manufacturing environment with two functional cells in Figure 6 to manufacture the part in Figure 7. Machines in each cell are different in nature but some have overlapping capabilities. For example, an identical milling machine in both cells may be a CNC and conventional milling machines, with the CNC having an attachment

that will enhance more operations to be performed on it than on the other machines. Machines also vary in age and accuracy, which helps in some cases to break ties between two competing machines. On the completion of the process, the system displays a graphical representation of the result. As highlighted in Figure 6, in the single cell selection, the two machines arrowed red were selected with almost 80% of the operations performed on one of the machines. In selecting combination of cells, the blue arrow shows the machines selected in each of the cells. This provides the flexibility needed in case of any interruptions such as machine failure that may hinder the timely completion of the part.



SUMMARY

This paper shows that considering the interrelationship among manufacturing functions will not only increase productivity but also help to simplify the manufacturing processes. Specifically, an alternate process planning approach has been developed by considering and demonstrating the interrelationship between two of the three major functions of manufacturing (process planning and group technology). This

CAAPP approach has been programmed using object-oriented techniques as a module aid to a scheduling system. In order to increase the flexibility of parts routing within a cellular manufacturing environment, more than one cell or a combination has been specified for the production of each part. These specifications are based on the individual capabilities of the machines rather than their types. For example, in the initial standard process plan, a drilling operation that originally was meant to be processed on a lathe now could have a radial drill as an alternative. Although this model is developed using a normal machine shop for sample run, it can be directly applied to or slightly modified to accommodate any manufacturing environment.

The implementation of the system in an object-oriented environment has also increased the maintainability of the program in that modules can be changed or replaced on a modular basis.

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