8-1991

Computer Aided Process Planning System for Generating Alternative Process Plans

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COMPUTER AIDED PROCESS PLANNING SYSTEM FOR GENERATING ALTERNATIVE PROCESS PLANS

by

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A Thesis
Submitted to the
Faculty of The Graduate College
in partial fulfillment of the
requirements for the
Degree of Master of Science
Department of Industrial Engineering

Western Michigan University
Kalamazoo, Michigan
August 1991

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Computer Aided Process Planning (CAPP) has a key role in Computer Integrated Manufacturing (CIM) as an interface between design and manufacturing. Current CAPP systems treat process planning as a static function, and always generate the same machine and process combinations. Thus, these CAPP systems are inadequate for advanced manufacturing facilities such as Flexible Manufacturing Systems (FMS). This thesis presents research conducted for the design and development of a CAPP system called Alternative Computer Aided Process Planning (A-CAPP) which generates alternative process plans by interacting with production planning and machine loading functions to satisfy system capacity constraints.

A-CAPP is a variant approach based process planning system and it uses 21-digit KK-3 code as its input. Two salient features of the A-CAPP system are: (1) it interacts with production planning functions and (2) it generates alternative process plans. This A-CAPP system exemplifies the feasibility of the proposed system.

ACKNOWLEDGEMENTS

I wish to express a special acknowledgement and sincere appreciation to my advisor and committee chair person, Dr. Tarun Gupta, for his encouragement, assistance, direction, and support throughout my course of study. I sincerely thank Dr. Gupta once again for his invaluable suggestions during this research.

My sincere thanks are due to my committee members, Dr. Richard E. Munsterman and Dr. Frederick Chen, for their advice, guidance, and assistance.

I thank the employees of CAE Center, Kalamazoo, MI, for their assistance during this research. Last, but not least, I thank all those who have helped me directly or indirectly in completing this research.

Rao T. Gali

Order Number 1345526

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CHAPTER I

INTRODUCTION

Manufacturing Trends

Manufacturing technology has developed so far, by a process of trial and error, with the emphasis being on unit cost reduction. In the future, however, major investments should not be looked at in isolation, but must reflect a beneficial effect on the whole organization (Leonard, 1987). The objective should not be to improve individual departments, nor install the most up-to-date technology, but rather to enhance the company's competitive position (Goldhar & Schlie, 1989). This means providing customers with the products they want, at the required specifications, quality, cost, and time. Here the need is to respond to rapid changes in sales volume and product mix, and constantly introduce new products or enhance existing designs (Goldhar & Schlie, 1989). Some improvements can be obtained by installing Computer-Aided Design (CAD) and/or Computer-Aided Manufacturing (CAM) (Leonard, 1987), but to achieve the overall performance that the market demands, it is necessary to operate the total company under a single game plan.

During the past two decades, the total manufacturing environment has been subject to a large scale change that is more radical than has occurred since the Industrial Revolution. The traditional drawing board has given way to the intelligent CAD terminal. Hard-wired numerical control (NC), which was originally viewed as a revolutionary new approach to component production, has rapidly been superceded by computerized numerical control (CNC), and now CNC machines themselves are being replaced by flexible manufacturing systems (FMS) (Leonard, 1987). Product design, material control, process planning, manufacturing, and marketing, together with financial control and spares/ servicing, have each been subject to intensive individual pressures for change as the computer finds an even wider application in industry (Leonard, 1987). Now the point has been reached where these departmental revolutions need to be embraced within a total company strategy as industry slowly evolves towards computer integrated manufacturing (CIM).

Process Planning

Process planning is the task of transforming part design specifications from detailed engineering drawings to a set of operating instructions necessary for part manufacture (Srihari & Greene, 1988). Alternatively, process planing is that function within a manufacturing facility that establishes which machining processes and parameters are to be used (as well as those machines capable of performing these processes) to convert (machine) a piece-part from its initial form to a final form predetermined (usually by a design engineer) from an engineering drawing (Wang, 1988).

Manufacturing planning, material processing, process engineering, and machine routing are the other names for process planning (Chang & Wysk, 1985). The process plan is frequently called an operation sheet, route sheet, operation planning summary, etc. In a more general sense, a process is called an operation (including manual operations) (Chang, 1982). The route is the operation sequence. The detailed plan usually contains the route, processes, process parameters, and machine and tool selections. The process plan provides the instructions for the production of the part. These instructions dictate the cost, quality, and rate of production. Therefore, process planning is the most important interface to both engineering design and manufacturing (Wang & Wysk, 1987).

The initial material may take a number of forms, the most common of which are bar stock, plate, castings, and forgings, or it may be just a slab of metal. With these raw materials as a base, the process planner must prepare a list of processes needed to convert the initial material into a predetermined final shape.

In a conventional production system, a process plan is created by a process planner who examines a new part engineering drawing, and then determines the appropriate operations/processes required to produce it. The previous experience of the process planner is critical to the success of the plan. Planning, as practiced today, is as much of an art as it is a formal procedure. There are numerous factors which affect process planning. The shape, tolerance, surface finish, size, material type, quantity, and manufacturing system itself all contribute to the selection of operations and the operation sequence (Chang & Wysk, 1985).

Figure 1 shows necessary forms of inputs and outputs of a process planning system. Inputs can either be provided interactively in the form of a Group Technology code or be accessed directly from the CAD data base. Required inputs to the process planning scheme include: geometric features, dimensional sizes, tolerances, materials, and finishes (Sundaram, 1986). These inputs are analyzed and evaluated in order to select an appropriate sequence of processing operations based upon specific available machinery and work stations. A process plan then needs to generate operational details or outputs, such as sequence

INPUTS:	OUTPUTS:
Geometric features	Sequence of operations
Dimensional sizes	Speeds & Feeds
Tolerances	Depth of Cut
Materials	Material removal rate
Finishes	Job Route

Figure 1. Inputs and Outputs of a Process Planning System.

of operations, speeds, feeds, depth of cut, material removal rate, and job route. As mentioned earlier, initial material used in a facility may take a variety of forms such as bar stock, slabs, plates, castings, and forgings (Steudel, 1984). From this description, it is obvious that process planning can be a very complex and time-consuming task requiring a large amount of data, and that it must be done well if the product is to be made correctly and economically.

In order to produce good, consistent, and accurate process plans, it is important that a logical and systematic procedure to develop, maintain, and update plans exists (Srihari & Greene, 1988). This requires the establishment and maintenance of a standard data base and the implementation of an efficient method to process the data.

Even though many efforts and accomplishments have been made in the last two decades to improve the productivity of design and manufacturing activities via computerized automation under the broad scope of CAD/CAM, it is rather unfortunate that the level of technology advancement in process planning is clearly lagging (Granville, 1990).

Importance of Process Planning

In a manufacturing production system, process planning has always been the most important interface between product design and manufacturing (Lin & Bedworth, 1988). Process Planning is performed in virtually all industries; its significance is the greatest in small batch, discrete parts metal fabrication industries. Recent manufacturing trends indicate that a wide variety of components are produced in batches of less than fifty in facilities that are usually poor in productivity (Kimemia & Gershwin, 1985). This has necessitated the development of efficient techniques to effectively plan and control production in these industries. Furthermore, with the emergence of Computer Integrated Manufacture (CIM) as a predominant thrust area in discrete parts industries, process planning has received significant attention because it is the link between CAD and CAM (Wolfe, 1985).

Need for Automating Process Planning

There are six main reasons for automating process planning. They are: (1) lack of qualified process planners, (2) complexity of the task, (3) inconsistency in manually generated process plans, (4) reduced product life cycles, (5) link between CAD and CAM, and (6) need for the incorporation of knowledge of continually new processes.

Lack of Qualified Process Planners

Process Planning is a task which requires a significant amount of both time and experience. According to the United States Air Force study (Chang & Wysk, 1985), a typical process planner is a person over 40 years of age, with long-term experience in a relevant production area. Although today the United States industry requires about 200,000 to 300,000 process planners, only 150,000 to 200,000 are currently available (Wang & Wysk, 1987). Automating process planning is an obvious alternative to eliminate this imbalance.

Complexity of the Task

Process planning is a tedious task. It requires a significant amount of experience and time on the part of process planners. Developing these process plans requires a lot of expertise. It involves a knowledge of materials, machines, processes, shop skills and practices, and related costs (Chang, 1982).

Inconsistency in Manually Generated Process Plans

Within a manufacturing plant, a product can be produced in several ways. Two process planners developing a plan for the same part are not likely to arrive at the same plan unless the part is very simple (Granville, 1990). Furthermore, manual process planning is very subjective; the quality of the plans depends on the experiences, preferences, and prejudices of the planner (Srihari & Greene, 1988). The result is a proliferation of plans.

Reduced Product Life Cycles

The period 1960-80 was a time of relatively long product cycles, leisurely rates of technology changes, geographical market segments, and domestic markets/competition. However, this was not the case in the 1980s, during which the markets/competition were shifted from domestic level to the international level, and the product life cycles were considerably reduced. Hence, in order to cope with the competition, process plans have to be generated as fast as possible. This can be done only through automating process planning function.

Link Between CAD and CAM

Process planning is the critical bridge between design and manufacturing. Process planning translates design information into manufacturing language. Today benefits of computerization in design as well as manufacturing functions are recognized. As a result of this, both CAD and CAM have been implemented. Integrating or bridging these two islands of automation requires process planning function to be automated (Chang & Wysk, 1985).

Need for the Incorporation of Knowledge of Continually New Processes

Today due to the increased competition, manufacturing technology is changing rapidly. Automation of the process planning function is necessary for incorporating this new technology or knowledge of new processes on a continuous basis.

Computer Aided Process Planning

Early attempts to automate process planning primarily consist of building computer-assisted systems for report generation, storage and retrieval of plans. When used effectively, these systems can save up to 40% of a process planner's time. A typical example can be found in Lockheed's computer-aided process planning (CAPP) system (Chang, 1982). This system does not perform the process planning tasks; rather, it helps to reduce the clerical work required of the process planner.

Perhaps the best known automated process planning system is the CAPP, developed by CAM-I (CAM-I stands for Computer-Aided Manufacturing International, a non-profit industrial research organization) (Chang & Wysk, 1985). In this automated process planning system, previously prepared process plans are stored in a data base. When a new component is planned, a process plan for a similar component is retrieved and subsequently modified by a process planner to satisfy special requirements. The technique involved is called variant approach.

Recent developments in computer-aided process planning have focused on eliminating the process planner from the entire planning function. Computer-aided process planning can reduce some of the decision making required during a planning process. It has the following advantages: (a) it can reduce the skill required of a planner, (b) it can reduce the process planning time, (c) it can reduce both process planning and manufacturing costs, (d) it can create more consistent process plans, (e) it can produce more accurate plans, and (f) it can increase productivity.

Two approaches to computer-aided process planning are currently being pursued: variant and generative. The variant approach uses library retrieval procedures to find standard plans for similar components (Wolfe, 1985). The standard plans are normally created by process planners. In a generative process planning system, process plans are generated automatically for new components from scratch without referring to the existing plans.

Benefits of CAPP

A survey by the society of manufacturing engineers identified some specific benefits that manufacturing engineering (process planning) can expect when a CAPP system is implemented (Wolfe, 1985). They are: (a) reduced clerical effort, (b) fewer calculation errors, (c) fewer oversights in logic or instructions, (d) immediate access to up-to-date information, (e) more detailed and more uniform plans, (f) use of latest revisions, (g) faster response to engineering or production changes, (h) more effective use of resources, and (i) consistent information.

CAPP also benefits other, less quantifiable areas like machine utilization, production and process planning lead times, production scheduling, capacity planning, product standardization, cost estimating, and producibility of parts.

Indeed, process planning can influence as much as 75% of production costs by determining how effectively a company uses its materials, labor, and machines (Granville, 1989). Recent studies on successful CAPP systems have shown that CAPP results in: (a) 47% reduction in part throughput time, (b) 35% improvement in process planning productivity, (c) 32% reduction in setup time, and (d) 7% reduction in total design costs (Granville, 1989).

Despite these benefits, less than 5% of all discrete parts manufacturers with over $40 million in sales have installed CAPP systems (Granville, 1989).

Flexible Manufacturing System

A CAPP system has special significance for a flexible manufacturing system (FMS). The aim of an FMS is to achieve the efficiency of high-volume mass production while retaining the flexibility of low-volume job shop production. An FMS is flexible since it allows production of virtually any volume and any combination of parts with approximately the same cost economics using several feasible routings and process options (Vonderembse & Wobser, 1987). This feature of an FMS calls for the CAPP system to have the capability of generating alternate process plans and give users an option for choosing a plan that satisfies production and capacity requirements (Srihari & Greene, 1988). The ultimate selection of the plan is largely determined on the basis of part mix and the availability of resources in the system.

The capability of generating alternate process plans is equally important for most conventional batch production systems as well. It has been observed that often the optimum plan recommended by a CAPP system cannot be implemented due to scheduling and loading constraints. The machine and/or equipment recommended in the plan may not be available at a specific time.

Problem Identification

Current CAPP systems treat process planning as a static function, and therefore, do not respond to the changing conditions of the manufacturing system. It means the present CAPP systems are not able to respond to the changes in the manufacturing environment. In other words, these CAPP systems always generate the same process plans (with the same process and machine combinations) irrespective of the current shop floor conditions. Thus, these systems are inadequate for most advanced manufacturing facilities such as FMS. For an FMS, a CAPP system should be capable of generating alternate plans and be able to let the user choose one plan that is most appropriate. In this research, an attempt was made to solve this problem. This thesis presents an architecture of a variant CAPP system which generates alternate process plans by interacting with production planning and machine loading functions. Furthermore, a prototype model of the proposed CAPP system, called alternative computer-aided process planning (A-CAPP), was developed to demonstrate the feasibility of the proposed CAPP system.

Some vital features of the developed system (A-CAPP) are: (a) it has modular structure, (b) it allows for interactive part coding, (c) it interacts with capacity planning and machine loading functions, and (d) it generates alternate process plans.

CHAPTER II

LITERATURE SURVEY

There are essentially four possible different approaches to process planning. They are: (1) traditional manual approach, (2) computer assisted variant approach, (3) computerized generative approach, and (4) artificial intelligence based approach. It may be more appropriate to use a particular approach under a given set of circumstances (Chang & Wysk, 1985).

Traditional Manual Approach

The traditional approach to process planning has been to manually examine an engineering drawing and develop a detailed process plan based upon the planner's knowledge of process and machine capabilities, tooling, materials, and shop practices (Boubekri, 1988). The process planner, given a specific material, must endeavor to build a list of processes to convert the given raw material into its desired final geometry. This process planning leans heavily upon the planner's knowledge and experience (Chang, 1982). It requires well trained, experienced personnel who are well versed in shop floor practice. A manual process plan will always exhibit personal preferences and prejudices

(Srihari & Greene, 1988). The traditional approach to process planning has some advantages and several disadvantages. Two advantages are its low investment cost and its flexibility. Disadvantages are the lack of consistency in identifying and in planning even similar parts, difficulty of specifying common tooling, and the difficulty of updating a manual file to reflect new processes and tooling (Wolfe, 1985). The challenge today is that many of the experienced process engineers are reaching retirement age and there are not enough process engineers waiting in the wings to replace them ("CAPP Brings Order to Process Planning," 1986).

Computer Assisted Variant Approach

A computer assisted, variant process planning system requires a catalog of standard process plans to be stored in a computer system (Chang, 1982). The part being planned is classified and coded using Group technology (GT) concepts.

The variant approach to process planning is similar to the traditional approach except that a computer is used to store and retrieve standard plans. With the part's attributes coded, a standard plan that is similar to the part being examined is retrieved (Chang & Wysk, 1985). The plan must then be checked, edited, and corrected. This system requires an experienced process planner to construct, maintain, modify, and edit standard process plans that are retrieved. In short, variant process planning uses the computer as a tool to assist the human. The planner's knowledge and experience are still the key factors in determining the quality of the resulting plans.

The variant system has been described by Chang in 1982 as follows: a variant system is one based upon the retrieval and extension of a standard manufacturing plan, with the identification of such plan resulting from an established decision rule. A standard plan in this case is a permanently established ordered sequence of fabrication steps for a specific category of mono-detail parts.

Some major disadvantages of the variant approach are: (a) the difficulty of constructing good standard plans; (b) the difficulty of maintaining consistency in editing practices; (c) inability to adequately accommodate various combinations of geometry, size, precision, material, quality, and shop loading rules; (d) the rather extensive keyboard activity required to enter and modify plans; (e) lack of transportability of the system; and (f) rather significant on-line data base requirements to accommodate stored plans and their modifications (Chang & Wysk, 1985).

The conditions under which the variant approach to process planning seems most viable are when: (a) the product design is fairly stable, (b) lot size is medium-high, (c) parts within a family are of similar size, (d) material type is the same for all members of the family, and (e) few engineering changes are normally made (Wang, 1988).

CAP, CAPP, AUTOPLAN and COMCAPP are some variant approach CAPP systems available (Wolfe, 1985).

Variant Process Planning System: An Example

An example will be used to show the step by step construction of a variant process planning system. In this example (Chang, 1982), a simplified coding system will be used. This process planning system will be used in a machine shop which produces a variety of small components. These components range from simple shafts to delicate hydraulic pump parts. The construction of this variant process planning system will be discussed in the following five steps, namely: (1) family formation, (2) data base structure, (3) search procedures, (4) plan editing, and (5) process parameter selection.

Family Formation

In a process planning system, family formation is based on production of parts or more specifically their manufacturing features (Chang & Wysk, 1985). Components requiring similar processes are grouped into the same family. Before any grouping can start, information concerning the design and processing of all the existing components must be collected from existing part and processing files.

Each component's design is coded by using the part code and the associated process plan is represented in another coded form which is called an operation plan code. An operation plan code represents a series of operations on one machine and/or one work station. For example, we can use DRL01 to represent load workpiece on drill press, attach a drill, drill holes, change drill to a reamer, ream holes, and unload workpiece from drill. Operations represented by an operation code are called an operation plan. An operation code does not necessarily include all operations required on a machine for a component. It is used to represent a logical group of operations on a machine, so that a process plan can be represented in a much more concise manner. Such a representation is called an operation code sequence. Since we do not want to lose the detail of a process plan, operation plans and operation code sequences must be stored properly.

The basic premise of an operation code is to simplify the representation of process plans. A simplified process plan can be stored and retrieved by a computer easily when represented in this way. It also can contribute to the family formation process. There are two methods that we can use to group parts into part families: (1) by observation, or (2) by computerized methods such as production flow analysis. It is obvious that when we have many components, the first method will be difficult to use.

Production flow analysis was first introduced by Professor J. L. Burbidge (Chang & Wysk, 1985) to solve the family formation problem for manufacturing cell design. Many researchers have subsequently developed algorithms to solve this problem. In production flow analysis, a large matrix is constructed. Each row represents an operation code, and each column in the matrix represents a component. We can define the matrix as $M_{i,j}$, where i designates operation codes, and j designates components ($M_{i,j} = 1$ if component j has operation code i, otherwise $M_{i,j} = 0$). The objective of the production flow analysis is to bring together those components which need the same or a similar set of operation codes in clusters (Chang & Wysk, 1985).

In 1979, King presented a rank order cluster algorithm which is quite simple in nature. Here, a rank order cluster algorithm will be used to show how component families can be determined in a machine shop. King's algorithm can be stated as follows.

Step 1. For each j, calculate the total weight of column j (W_j).

$$W_j = \sum_i 2^i * M_{i,j}$$

Step 2. If W_j values are in an ascending order, go to step 3. Otherwise, rearrange the columns to make W_j values fall in an ascending order.

Step 3. For each i, calculate the total weight of row i (W_i).

$$W_i = \sum_j 2^j * M_{i,j}$$

Step 4. If W_i values are in descending order, stop. Otherwise, rearrange the rows to make W_i values fall in an ascending order.

Go to Step 1 (Chang & Wysk, 1985).

King's algorithm can only handle problems with a few machines as well as components. The number of machines and components is constrained by the computer word size (16 machines and components for a 16-bit word computer). However, King and Nakornchai later found that this limitation can be remedied by partial sorting (Chang & Wysk, 1985).

Data Base Structure

The variant process planning system contains only a small amount of information as opposed to an industrial application where thousands of components and process plans need to be stored and retrieved. Because of the large amount of information, the data base system plays an important role in variant process planning. A data base is no more than a group of cross referenced data files. The data base contains all the necessary information for an application, and can be accessed by several different programs for specific applications. There are three approaches to construct a data base: hierarchical, network, and relational. Although the concept and structure for these approaches are very different, they all can serve the same purpose.

For commercial programming, there are several available data base management systems such as CODASYL, MARKIV, SPIRES, etc. These systems are high-level languages for data base construction and manipulation (Chang, 1982). Of course, a data base can always be written using procedural languages such as COBOL, FORTRAN, PL/I, etc. No matter what approach and language is used, the basic structure of the data base keeps the same form (Chang & Wysk, 1985).

Search Procedure

Once the preparatory stage has been completed, the variant planning system is ready for production. The spirit of a variant system is to retrieve process plans for similar components. The search for a process plan is based on the search of a part family to which the component belongs. When the part family is found, the associated standard plan can be easily retrieved.

A family matrix search can be seen as the matching of the family matrix with a given code. Family matrices can be considered as masks. Whenever a code can pass through a mask successfully, the family is found. The search procedure can be described as follows.

Let C_j be a value of code position j for the given component.

P_n is a pointer for family matrix 1, which links to the next family matrix.

P_s is a pointer for family matrix 1, which links to the directory of the standard plan file.

The following algorithm can be used to find a standard plan.

Step 1. For all i, do step 2. End, stop.

Step 2. For j = 1 to J do step 3; end, go to step 5.

Step 3. i = C_j

If P_{lij} <> 0; end step; otherwise,

Step 4. 1=P_{lij}; go to step 2.

Step 5. Standard plan found, Ps is the pointer to the standard plan file. Terminate.

Plan Editing and Parameter Selection

Before a process plan can be issued to the shop, some modification of the standard plan is necessary, and process parameters must be added to the plan. There are two types of plan editing: one is the editing of the standard plan itself in the data base, and the other is the editing of the plan for the component. Editing a standard plan implies that a permanent change in the stored plan be made. This editing must be handled very cautiously, because the effectiveness of the standard plan affects the process plans generated for the entire family of components. Aside from the technical considerations of file maintenance, the structure of the data base must be flexible enough to accept expansion additions and deletions of data records. As a result, the pointer system in variant process planning may prove to be efficient.

Editing a process plan for a component requires the same expertise as editing a standard plan. However, it is a temporary change; and therefore does not affect any other component in the family. During the editing process, the standard plan needs to be modified to suit the specific needs of the given component. Some operations need to be removed; others must be changed. Additional operations may also be required to satisfy the design. A text editor is usually used at this stage.

A completed process plan includes not only operations but also process parameters. Process parameters can be found in machining data handbooks or can be calculated using optimization techniques. The first approach is easier.

Computerized Generative Approach

Generative process planning can be concisely defined as a system that synthesizes process information in order to create a process plan for a new component automatically (Wang, 1988). In a generative process planning system, process plans are created from information available in a manufacturing data base without human intervention (Lawler, 1990). Upon receiving the design model, the system can generate the required operations and operations sequence for the component. Knowledge of manufacturing must be captured and encoded into efficient software. By applying decision logic, a process planner's decision making process can be imitated. Other planning functions, such as machine selection, tool selection, process optimization, and so on, can also be automated using generative planning techniques (Chang & Wysk, 1985).

Four major advantages of the generative approach based process planning systems are: (1) consistent process plans can be generated very rapidly, (2) new components can be planned as easily as existing components, (3) it does not require human intervention, and (4) it can potentially be interfaced with an automated manufacturing facility to provide detailed and up-to-date control information (Srihari & Greene, 1988).

Decisions on process selection, process sequencing, and so on, are all made by the system (Wang & Wysk, 1986). However, transforming component data and decision rules into a computer-readable format is still a major obstacle to be overcome before generative planning systems become operational. Successful implementation of this approach requires the following key developments: (a) the logic of process planning must be identified and captured, (b) the part to be produced must be clearly and precisely defined in a computer-compatible format (e.g., three dimensional model, GT code, etc.), and (c) the captured logic of process planning and the part description data must be incorporated into a united manufacturing data base.

Today, the term generative process planning is relaxed from the definition given above to a less complete system (Lin & Bedworth, 1988). Systems with built in decision logic are often called generative process planning systems. The decision logic is usually an ability to check some conditional requirements of the component and select a process. Some systems have decision logic to select several process plan fragments and combine them into a single process plan (Chang & Wysk, 1985). However, no matter what kind of decision logic is used and how extensively it is used, the system is usually categorized as a generative system.

Ideally, a generative process planning system is a turn key system with all the decision logic contained in the software. It possesses all the necessary information for process planning; therefore, no preparatory stage is required. This, however, is not the case in the existing generative systems.

Generative process planning systems can be further divided as those that use forward planning, and those that use backward planning (Srihari & Greene, 1988). Forward planning involves modifying the workpiece until it attains the features required by the finished product. Backward planning involves starting with the finished product, and filling in to the shape of the unmachined workpiece. Each machining process is considered as a filling process.

AUTAP, AOTOTECH and APPAS are some generative approach based CAPP systems available (Chang & Wysk, 1985).

Artificial Intelligence Based Approach

Recently, the field of artificial intelligence (AI) has advanced to the point where AI techniques are beginning to produce promising results both in academia and in industry. AI can be defined as the ability of a device to perform functions that are normally associated with human intelligence (Chang & Wysk, 1985). These functions include reasoning, planning, and problem solving. Some of the AI applications involve design and development of expert systems. An expert system is defined as an intelligent computer program which uses domain-specific knowledge to achieve a high level of performance in a field which would normally require a human expert (Gupta, 1990). For a complex problem like one for generating a process plan, an expert system is gradually replacing traditional CAPP methods. A few systems, namely GARI (Descotte & Latombe, 1983), Technostructure of Machining TOM, PROPLAN, Hierarchical and Intelligent Manufacturing Automated Process Planner HI-MAPP, Semi-Intelligent Process Planner SIPP, and micro-computer based Turbo-CAPP have been reported (Gupta, 1990).

In an expert system, the knowledge of human experts is represented in an appropriate format. The most common approach is to represent knowledge by using rules (Gupta & Ghosh, 1989). Rule-based deduction is frequently used to find an action. There are two types of knowledge involved in process planning systems: component knowledge and process knowledge (Chang & Wysk, 1985). The component knowledge defines the current state of the problem to be solved (it is also called declarative knowledge). On the other hand, the knowledge of processes defines how the component can be changed by processes (it is also called the procedural knowledge). Applying the process knowledge to a component in a logical manner is called control knowledge. Control knowledge is similar to human knowledge in reasoning, which deduces certain facts from the knowledge base concerning a problem. This can be very difficult to program on a computer.

In 1980, Nilsson listed three control strategy approaches (Chang & Wysk, 1985). They were: (1) a control strategy problem can be solved by another AI production system, (2) a control strategy problem can be solved through the use of AND/OR solution graphs, and (3) a control strategy problem can be solved through incorporating the control knowledge in the form of rules. The rule also acts like a program.

There are several advantages in the use of an expert system approach for CAPP function (Gupta, 1990). Some of them are discussed here:

1. The generation of a process plan requires consideration of a number of factors which influence selection and sequencing decisions for processes, and their important parameters (Gupta, 1990). Normally, a plan begins with the process selection followed by machines and tool selection. The decision process, adequate for producing a complete

process plan, requires creation of a hierarchy consisting of several levels. Each level would be ideally required to have a defined domain for deciding specific parameters of the plan. Also, since a decision at any level can generally influence those at any other level, the system should have the capability of back tracking its partially developed solution from almost any stage. The expert system approach has a potential to provide a good solution to meet these requirements.

2. Decision trees and tables, often used in traditional generative CAPP systems, work effectively only for simple decision making processes (Gupta, 1990). These are primary methods to describe knowledge and are coded line by line in the program. Any modification to the current knowledge would require rewriting of at least some portion of the original program. For example, the value of a tolerance, which makes program-processing branch off, is described in the data file. The user can fit the program to his/her organization only within the range of modifications that can be made out of the values in the data file. To totally automate the process planning function, the system must be able to perform certain level of intelligent reasoning. An expert system organizes the domain knowledge and employs inference mechanism to reason intelligently.

3. A productive CAPP system must have access to a

tremendous amount of information which includes facts about machines in a manufacturing system, rules about selecting and sequencing machining operations, and all necessary machining parameters (Gupta, 1990). Furthermore, the system should be flexible because facts and rules in the data base require constant updating. As new technology, equipment, and processes become available, the most effective way to manufacture a particular part also changes. An expert system stores knowledge in a special manner so that it is possible to add, delete, and modify its knowledge base without recoding the program.

Factors Affecting the Selection of a Particular Approach

The process planning function is manufacturing system dependent (Chang & Wysk, 1985). That is, no one single process planning system can satisfy all of the different manufacturing systems needs. There are several factors that must be considered when one attempts to implement a process planning system. These factors include: (a) manufacturing system components, (b) production volume/ batch size, and (c) number of different production families (Chang, 1982). These factors are discussed here.

Manufacturing System Components

The planning function is directly affected by the capability of the manufacturing system which will be used to produce the component (Chang, 1982). A manufacturing system which has precision machining centers can produce most of its products on a single machining center. However, in other systems several additional processes and machines may be required in order to achieve the same precision. This is true for process and machine selection, and even more true for parameter selection or optimization. Process knowledge depends on the manufacturing system.

A variant process planning system contains no process knowledge per se. Process plans are retrieved from a data base. The standard plans in the data base were manually prepared by human process planners. The capability of the manufacturing system was taken into account by the process planners when they prepared the process plans. Consequently, the standard plans must be changed when major factory renovation takes place. Variant process planning structures have been adopted by different manufacturing systems; however, the data base must be rebuilt for each system. The lengthy preparatory stage is unavoidable. Implementation of a variant planning system requires that a unique data base of component families and standard plans be constructed (Chang & Wysk, 1985).

On the other hand, a generative process planning system has its own knowledge base which stores manufacturing data. The user modifies the knowledge base in order to suit his/her system. The process knowledge representation can be created and stored using several methods. It is essential, however, that the user interact with the system so that he/she can easily change the process knowledge base. This must be considered when purchasing/creating a generative process planning system.

Production Volume/Batch Size

Production volume is a major consideration in the selection of production equipment (Chang & Wysk, 1985). As a basic rule of thumb, special purpose machines and tooling are used for mass production, and general purpose equipment is used for small batch production. The economics of production determines this decision.

Different process plans should be used for the same component design when the production volume is significantly different. For example, it is appropriate to turn a thread on an engine lathe if we only need one screw. However, when 10,000 screws are required, a threading die should be considered. Machining a casting is also more desirable than complete part fabrication for large production volume.

In a variant process planning system, the production volume can be considered included as a code digit.

However, standard plans must be prepared for different levels of production. Preparing standard plans for each production level may not be feasible, since components in the same family may need quite different processes when the production volume increases. When the batch size is not included in the family formation, manual modification of the standard plans for different production volume is necessary.

In a generative process planning system, the production volume can be considered a variable in the decision model. Ideally, the knowledge base of a system includes this variable. Processes, as well as machines, and tool selection are based not only on shape, tolerances, and surface finish but also on the production volume.

Number of Different Production Families

The number of different production families used is a function of how different the components being planned are. A variant process planning system is of little value if there are many families and few similar components (family members), because the majority of the effort will be spent adding new families and standard plans (Wang, 1988). A generative process planning system is more desirable for this type of manufacturing environment.

Certain manufacturing systems specialized in making similar or identical components for different assemblies. These components can usually be designated by their features. Since each feature can be machined by one or a series of processes, a model can be developed for each family. In the model, processes corresponding to each feature are stored. A process plan can be generated by retrieving processes which corresponds to the features on a new component. This type of generative process planning system utilizes the major benefit of group technology. It is easier to build this type of system than a generative process planning system, yet it can provide very detailed plans.

For a moderate amount of component families and many similar components in each family, a variable process planning system is usually the most economic automated planning alternative (Chang, 1982). Although a long variant preparation stage is still necessary, a variant process planning system is much easier to develop. Such a system can be very effectively used when there are many similar components. On the other hand, significant product variation usually dictates generative process planning as the most economical alternative.

Group Technology

A significant and valuable tool for the development of

CAPP is group technology (GT), which can be characterized as "the operating management philosophy based on the recognition that similarities occur in the conception, design, sale, manufacture, and support of discrete products" (Chang & Wysk, 1985, p. 53). By using GT, parts with similar attributes can be classified and coded into part families to simplify and speed up process planning and manufacturing (Guerrero, 1987a). The benefits of utilizing GT in the entire manufacturing process have been reported to have 10% to 80% savings in part design and drawing, production and quality control costs, setup and throughput time, raw materials, work-in-process, and finished goods inventory (Guerrero, 1987a).

GT Part Family and Code Structures

The part family concept is a traditional group technology application in which related parts with similar attributes such as geometric shape or manufacturing process requirements are grouped (Chang, 1982).

From a manufacturer's point of view, part similarities are identified according to the common manufacturing processes required to make the parts. An example is that similar external and internal shapes of rotational parts can be fabricated by the same type of machine operation, say turning. This machine operation oriented classification and coding method can provide an excellent interface between design and manufacturing.

When constructing a coding system for a component's representation, there are several factors to be considered. They include: (a) the population of components (rotational, prismatic, deep drawn, sheet metal, etc.), (b) the detail the code should represent, (c) the digital representation (binary, decimal, octal, alphanumeric, hexadecimal, etc.), and (d) the code structure (chain, hierarchical or hybrid).

Though there are several GT coding schemes such as OPITZ, MICLASS, CODE, KK-3, DCLASS and COFORM, the KK-3 coding system is the most popular and convenient system (Chang & Wysk, 1985). The structure of the KK-3 code is described in Chapter IV.

CHAPTER III

CAPP AND ITS RELEVANCE TO FMS

CAPP-CIM Link

With the emergence of CIM as a predominant thrust area in discrete parts industries, CAPP has received significant attention because it is the link between CAD and CAM (Chang & Wysk, 1985). Integration of CAD and CAM could be brought about ideally through the use of CAPP (Lin & Bedworth, 1988). An ideal CIM scenario could include several important functions that take place between product design using CAD and manufacturing using CAM. These functions would include: procurement of raw material inventory at the optimal time, process planning, release of jobs to the facility, scheduling, and sequencing of parts through the facility, facility loading, creation, and loading of manufacturing instructions for a specific part for the CNC machine that will manufacture it, and so on (Srihari & Greene, 1989). The CAPP system will play a crucial role in the implementation of each of these functions. It is indeed an integral part of the CIM function that interacts in a dynamic manner with the other constituents.

CAPP in a Dynamic Manufacturing Environment

The primary objective of most computer aided process planning systems has been to develop a sequence of operations based upon technical and economic criteria (Srihari & Greene, 1988). This approach is static in nature and does not consider dynamic facility conditions. A versatile manufacturing system requires a CAPP that is dynamic in nature, since it could possibly produce parts using several job routes using alternative machines and processes. Dynamic process selection must ensure the ability to generate alternative feasible plans using different routes (Srihari & Greene, 1988). It involves the ability to decide which process would be used to manufacture a part, taking into consideration the current facility status. This technique also assumes that alternative processes exist to machine a part, and can be used in facility configuration decisions to help decide the number of machines that are needed in the facility, whether a smaller number of faster, sophisticated machines or a larger number of slower and cheaper machines could be used.

In 1982, Nof and Barash stated that production rate and machine utilization are two criteria to be monitored in a facility (cited in Nof & Barash, 1987). It was found that when dynamic allocation of either the original plan or the alternative plan were undertaken, the production rate and machine utilization improved. However, product quality may be dependent upon the manufacturing process used. In a particular facility, since most parts are not manufactured just once, but repetitively, over a long period of time in different product mix and load conditions, it would be most desirable to have a CAPP system which can generate alternate process plans for each part.

Several CAPP systems have been developed to date. These systems are designed to provide a vital link between CAD and CAM and thus reducing manufacturing lead time. As mentioned earlier, their approach is static in nature and does not consider dynamic resource conditions. It means that the present CAPP systems are not able to respond to the changes in the manufacturing environment. When facing a dynamic situation, the response of a CAPP system to changes in system resources will determine its success within CIMS. The sources of manufacturing environment changes can be categorized into following categories: (a) machine availability, (b) tool/fixture availability, and (c) part design changes.

Machine Availability

The status of machine availability is not always steady. Machine breakdown, machine schedule, scheduled/ unscheduled maintenance, and new machines brought in will all change the machine availability.

Tool/Fixture Availability

Cutting tools have limited life. A cutting tool which was previously available for processing the same part may not be available now due to its failure, scheduled/unscheduled maintenance, and present schedule. Further new tools brought in may also affect the status of tool availability.

Part Design Changes

Low volume, high variety, and shorter life cycles are current worldwide trends in the manufacturing industry. The part design always requires minor modifications for different models. To cope with this challenge, a CAPP system has to respond fast enough to generate route sheets with the required minor changes.

Based on these three types of manufacturing information changes, a CAPP system should be able to recommend alternate (a) machines and (b) processes. It is this important requirement which is not available in existing CAPP systems. Such a CAPP system is practical as well as feasible. Hence, this research presents design and development of a CAPP system which is able to respond to the dynamic manufacturing environment.

Emergence of Flexible Manufacturing Systems and the Need for Generating Alternative Process Plans

The period of 1960-80 had relatively long product cycles, leisurely rates of technology changes, geographical market segments, and domestic markets/competition. Computer assisted process planning systems were developed in this period, which significantly improved overall productivity in various planning functions. These computer assisted process planning systems were viewed as a revolutionary new approach to manufacturing. In the 1980s, product life cycles were considerably reduced, and the markets/competition were shifted from domestic level to the international level. The computer assisted process planning systems, which were originally viewed as a revolutionary new approach to manufacturing, were not a satisfactory response to these demands.

Flexible manufacturing systems (FMS) have emerged as an offspring of technological innovation in computers and NC techniques as a result of the market trends of shorter product life cycles and the demand for larger product variations (Gupta, 1988). An FMS is an integrated system of computer controlled machine tools connected to a centrally controlled automated material handling system. Thus, an FMS combines the flexibility of the job shop with the efficiency of a transfer line (Hutchinson, 1985). The advantages of an FMS are as follows: (a) increased machine utilization, (b) reduced manufacturing lead time, (c) reduced work in process inventory, (d) scheduling flexibility, and (e) reduced machine bottlenecks (Das & Khumawala, 1989).

In an FMS, a given operation on a job can be performed at several machines due to the capability of machines to load multiple tools (Byrkett, Ozden & Patton, 1988). Entering workpieces, thus, have several different machine choices. Further, a job in an FMS, unlike the one in a traditional job shop, can be processed by different operations. As a result of these two factors, a job in an FMS can go through alternate routes before its completion. Because of this increased flexibility, job scheduling in an FMS becomes dynamic and often regarded as a real time function. Also, job scheduling is a real time function in any manufacturing system. This aspect holds true for traditional as well as advanced manufacturing facilities such as an FMS. In the absence of alternate process plans, neither will the job be completed nor the actual capabilities of the system facility explored. Productivity can be dramatically improved by selecting an efficient routing. In other words, to take full advantage of FMS, proper selection of tools, machines, and machine sequence is important. Hence, when deciding on the actual sequence of operations and the ultimate job route, dynamic shop floor conditions, as well as all possible routes and manufacturing operation sequences are to be considered. At present, even a true generative CAPP system cannot meet this requirement.

A versatile flexible manufacturing system requires a CAPP that is dynamic in nature. Dynamic process selection must ensure the ability to generate alternative feasible plans using different routes. In a particular facility, since most parts are not manufactured just once but repetitively, it is a sound decision to prepare alternative process plans for each part. It should also involve the ability to decide which process would be used to manufacture a part, taking into consideration current facility status. This technique should also consider the fact that alternative processes exist to machine a part, and can be used in facility configuration decisions to help decide the number of machines that are needed in the facility, whether a smaller number of faster, sophisticated machines or a larger number of slower and cheaper machines could be used. Hence, in the future, research should be focused to develop dynamic CAPP systems, which will be able to generate alternate process plans.

Significance of CAPP for an FMS

A CAPP system has special significance for an FMS. The aim of an FMS is to achieve the efficiency of high-volume mass production while retaining the flexibility of low-volume job shop production. An FMS is flexible since it allows production of virtually any volume and any combination of parts with approximately the same cost economics using several feasible routings and process options. This feature of an FMS calls for the CAPP system to have the capability of generating alternate process plans and gives users an option for choosing a plan that satisfies production and capacity requirements. The ultimate selection of the plan is largely determined on the basis of part mix and the availability of resources in the system. Issues surrounding an FMS can be grouped into five categories: design, aggregate planning, system setup, scheduling, and control.

The capability of generating alternate process plans is equally important for most conventional batch production systems as well. It has been observed that often the optimum plan recommended by a CAPP system cannot be implemented due to scheduling and loading constraints. The machine and/or equipment recommended in the plan may not be available at a specific time.

CHAPTER IV

DESIGN METHODOLOGY

Thus far, several topics related to process planning have been discussed. The input to process planning systems, approaches to process planning, need for automating process planning, the role played by CAPP in an FMS, different approaches to process planning, and the need for linking process planning and production planning functions of FMS have all been discussed in detail. This chapter presents an integrated approach to link process planning with production planning functions. In this chapter, an approach to link process planning with capacity planning and machine loading functions is presented.

The discussion in this chapter focuses on the modular approach to process planning. An architecture of a process planning system called Alternative Computer-Aided Process Planning (A-CAPP) system is presented. The organization of A-CAPP along with its salient features and structure is discussed. A-CAPP is developed using QUICKBASIC language on a personal computer.

Methodology for Integrating CAPP and FMS Planning

The proposed methodology for integrating CAPP and FMS planning is shown in Figure 2. The integration methodology starts from the aggregate planning, resource grouping, loading, determination of a feasible plan, and finally the determination of a schedule for implementation. It considers the loading of part families to each cell in the FMS. Each cell is generally known as a flexible manufacturing cell (FMC). The total workload of a part is divided into batches, based on the demand for a planning period. Different batches of a part mix required in the planning period will determine the part production schedule (PPS). These steps are same as in Kusiak's FMS planning and scheduling methodology (Kusiak, 1990).

The proposed CAPP system will use the parts scheduled in the PPS and their detailed design drawing as input to generate the alternative process plans for each part type. Because each part type has multiple process plans and there are possibly two or more part types scheduled for production during a planning horizon, several process plan combinations can be obtained.

A simulation model can be developed to evaluate these process plan combinations. The plan combination that is feasible and satisfies other constraints such as due date can be selected by the user. The simulation model will use

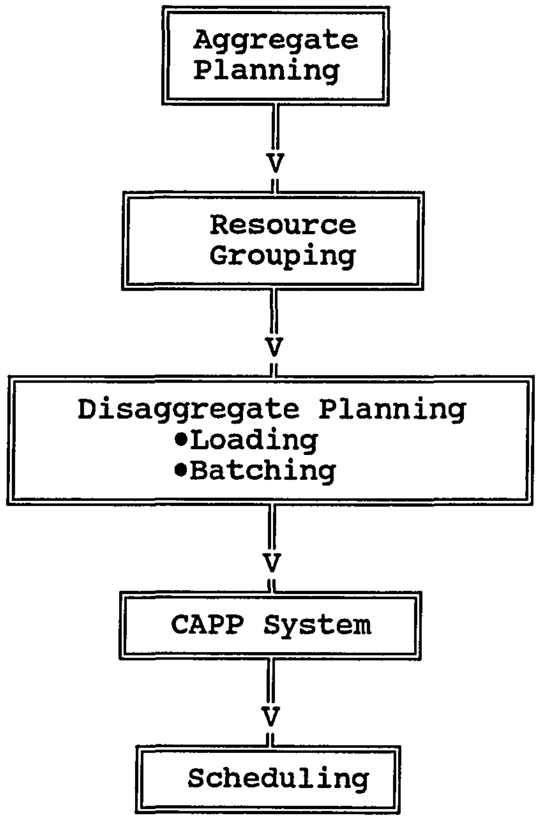

Figure 2. Methodology for CAPP and FMS Planning Integration.

the batch sizes of each part type and process plan combinations as input to evaluate the alternative plan combinations and to predict the FMS performance. Therefore, the production manager may select the best plan combination, based on a criterion that best meets the business goals. Due date commitments and cost minimization are often found to be important objectives. Thus, the manager can choose a plan combination which has the best system performance to meet the delivery time requirements, or he/she may pick up some combinations to do the cost optimization and dispatch the process plan which has the least cost.

The most important step in the implementation of the proposed methodology is the development of a CAPP system, which can generate alternative process plans by interacting with production planning functions. In order to demonstrate the significance of the proposed methodology, a CAPP system, called A-CAPP, was developed. Figure 3 is the flow diagram of the proposed CAPP system.

A-CAPP Architecture and Design Philosophy

An Overview

A-CAPP is a variant process planning system, and it uses group technology based part code as its input. In A-CAPP, logical divisions of process planning activity are

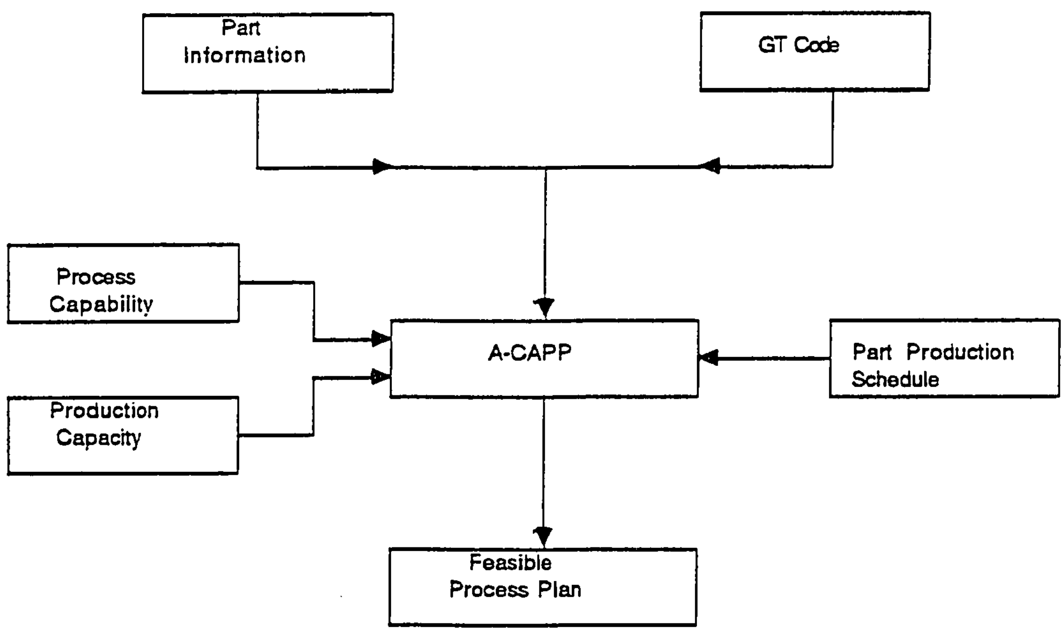

Figure 3. Flow Diagram of the Proposed CAPP System.

broken into functional modules. The major modules of A-CAPP are: (a) coding, (b) family search, (c) editing, (d) process selection, (e) machine selection, and (f) capacity search. These modules are discussed later in this chapter.

In A-CAPP, a part is represented by 21-digit KK-3 code. The KK-3 code contains the information necessary for describing the part as well as for process planning. Due to the complexity of the system, A-CAPP is confined to rotational parts.

In A-CAPP, an incoming part either can be coded interactively or the code can be entered directly. Based on the KK-3 code, the family search module identifies the family to which this part belongs. The classification of parts into part families is based on six vital features of the parts. In other words, parts are classified into part families based on six digits of the 21-digit part code. Therefore, every part family has a six-digit family code.

The family search module also finds whether a standard plan for the family to which this part belongs exists in the data base or not. If the standard plan does exist in the data base, then the standard plan is retrieved automatically and the editing module gets activated. If the standard plan does not exist in the data base, then the standard plan module gets activated and asks the process planner to create the standard plan for the part family.

Immediately after creating the standard plan, control passes to the editing module.

The editing module lets the process planner edit the existing/newly created standard plan. The two options available in A-CAPP editing are adding an operation or deleting an operation. Once editing is done, control passes to process selection module. At this stage, the process planner has two capacity options available. They are starting with the initial machine capacities or starting with the current machine capacities. The process selection module allows the user to select a process and a machine out of all the available processes and machines. The system updates the capacity of the machine the user has selected.

Design Considerations

A-CAPP is a variant approach based process planning system. The major concept used in designing A-CAPP is to construct a generic framework for a modular system. The system interacts with capacity planning and machine loading and can be expanded easily. A partial list of its vital features includes the following: (a) it has modular structure, (b) it allows for interactive part coding, (c) it interacts with production planning functions (capacity planning and machine loading), and (d) it generates alternate process plans.

Modular Structure

Designing and developing a process planning system itself is a complex task. Thus, designing and developing a process planning system which can interact with capacity planning and machine loading conditions is even more complex. Hence, if one were to design and develop the entire system as a whole, then it would be very difficult. The system would also be too complex to understand. Expansion or modification of the system would be extremely difficult. However, using a modular approach to decompose the tasks and construct modules for each decomposed function makes it achievable. Each module uses its input to create output and is functionally separate from other tasks. However, through data input and output these modules interact with each other and achieve total process planning.

Since each module contains a decomposed subtask, the planning tasks become more meaningful and are more easily understood. Expansion and modification of the system are possible by simply modifying these modules. After a solution technique for a missing function is developed, the corresponding module can be changed easily to interface with other modules.

The process planning can be divided into the following sub tasks: (a) interactive part coding, (b) family search (part family identification and part family standard plan identification), (c) generation of standard plans, (d) editing standard plans, (e) process selection, (f) machine selection (candidate machine extraction and a machine selection), and (g) capacity search. In the A-CAPP system, each of these listed subtasks is constructed as a software module. These modules are discussed later in this chapter.

Interactive Part Coding

A-CAPP uses 21-digit KK-3 code as its input. The code structure for rotational components is shown in Table 1. In A-CAPP, the coding module allows the user to code the part interactively.

The KK-3 code includes two digits for component name (functional name) classification. The KK-3 code also classifies materials using two-code digits. The first digit classifies material type, and the second digit classifies the shape of the raw material. Dimensions and dimensional ratios are classified using the next three digits. Shape details and process type are classified in KK-3 using thirteen digits of code. Of these thirteen digits, six digits are used for the classification of external surface, three digits are used for the classification of internal surface,

Table 1

Structure of the KK-3 Code for Rotational Components

Digit	Classification Items
1	Part name: General classification
2	Part name: Detail classification
3	Material: General classification
4	Material: Detail classification
5	Major dimensions: Length
6	Major dimensions: Diameter
7	Ratio of major dimensions
8	External surface: Outer primary shape
9	External surface: Concentric screw threaded parts
10	External surface: Functional cut-off parts
11	External surface: Extra ordinary shaped parts
12	External surface: Forming
13	External surface: Cylindrical surface
14	Internal surface: Internal primary shape
15	Internal surface: Internal curved surface
16	Internal surface: Flat and cylindrical surface
17	End surface
18	Non concentric holes: Regularly located holes
19	Non concentric holes: Special holes
20	Non cutting process
21	Accuracy

one digit is used for the classification of end surface, the next two digits are used for the classification of non-concentric holes, and one digit is used for the classification of non-cutting processes. Finally, the last digit is used for the classification of accuracy levels.

Interface With Production Planning Functions

Several CAPP systems have been developed to date. These systems were designed to provide a vital link between CAD and CAM thus reducing manufacturing lead time. As mentioned earlier, their approach is static in nature and does not consider dynamic resource conditions. It means the present CAPP systems are not able to respond to the changes in the manufacturing environment. Hence, in A-CAPP an attempt is made to interact with the resource conditions (in other words, updated machine capacities).

In A-CAPP, the capacity module interacts with the updated machine capacity file and finds the available capacity for each candidate machine. Since the process planner knows the shop floor conditions well in advance, he/she can select the best machine out of all the available machines. If the process planner wants to balance the load on different machines, then he/she can select a machine (out of all the machines available for that operation) which has more available capacity. Once the planner selects a machine the system ensures that the selected machine has sufficient remaining/balance capacity. If the selected machine does not have sufficient capacity, then the system will ask the process planner to select another machine. If a machine which has sufficient capacity is selected, then the system automatically updates the capacity of that machine.

In this way, A-CAPP system ensures that the process plan generated is feasible, and is based on the current shop floor conditions.

Generation of Alternative Process Plans

A-CAPP system displays the alternative processes and machines for any operation to the process planner, and allows the user to select a process and a particular machine. Along with the alternative processes and machines, the system also displays to the process planner the capacity of each alternative machine. Hence the planner can select a process and a particular machine based on the current shop floor conditions. This is the most important feature of the developed A-CAPP system, which is not available in any of the existing familiar CAPP systems. In the existing CAPP systems, process plans for a part are always created with the same processes and machines irrespective of the shop floor conditions. Hence, the process plans generated with these systems are often infeasible.

This problem is resolved in the A-CAPP system by letting the process planner select a process and a particular machine for each operation. The system first presents the various alternate processes in preferential order and then presents alternate machines that can perform the selected process. If the process planner selects a machine which has insufficient capacity, the system gives an insufficient capacity message and asks the planner to select another machine. In this way, the process planner can use A-CAPP to generate process plans, which satisfy production capacity constraints.

Furthermore, since any manufacturing facility produces more than one part, there will be some machine combination/ combinations which will be best suited to any part production at that time. Through generating/creating different process plans in different conditions of shop floor, the process planner can create the machine combination which is feasible at a given time.

Operation Stages of A-CAPP

A-CAPP is a variant process planning system. As mentioned in Chapter II, any variant process planning system has two operation stages, a preparatory stage, and a production stage. Hence, A-CAPP system also has two operation stages, namely, the preparatory stage and the production stage. Hence, the A-CAPP system is described here in terms of the two operation stages.

Preparatory Stage

During the preparatory stage the existing components are coded, classified, and subsequently grouped into families. A standard process plan for each part family is then created by the process planner and stored permanently in the standard plans database.

Because an operation may be processed by different processes (alternate processes), a part family may have one or more alternate standard plans. Furthermore, each of these alternate processes may be carried on different machine tools. Therefore, an operation may use one or more alternate machines. The flow diagram of the preparatory stage is shown in Figure 4.

Production Stage

In the production stage, an incoming component is first assigned a KK-3 code which is then input to a part family searching routine to find the family to which the component belongs. The part family code is then used to retrieve the standard process plan. The process planner

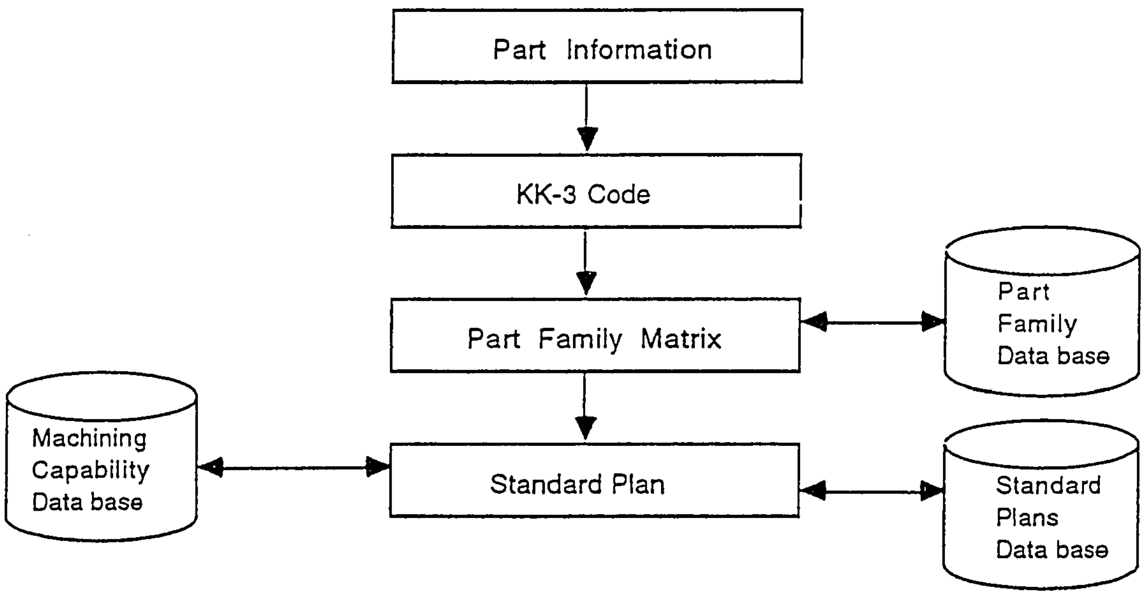

Figure 4. Flow Diagram of the Preparatory Stage.

may modify the standard plan to satisfy the component requirements. Because there may be more than one machine used in each operation in a standard plan, the process planner has to select one machine for each operation.

By using the part's detailed information as input and matching the condition of the machining capability, the system is able to calculate the machining time for each operation. By comparing this calculated machining time with the available machine capacity, the system will determine whether the machine selected has sufficient capacity or not. If it does not have sufficient capacity, then the system asks the process planner to select another machine. Once a machine with sufficient capacity is selected, then the system automatically updates the capacity of that machine. The flow diagram of the production stage is shown in Figure 5.

A-CAPP Data Structure

An optimum design for the record structure is the key to efficient storage and retrieval of large volume of data. The data structure is the most fundamental element of strong information flow in A-CAPP. This is because, in any variant process planning system, process plans are retrieved, edited, and stored continuously; and A-CAPP is a variant system. Furthermore, due to the interaction of

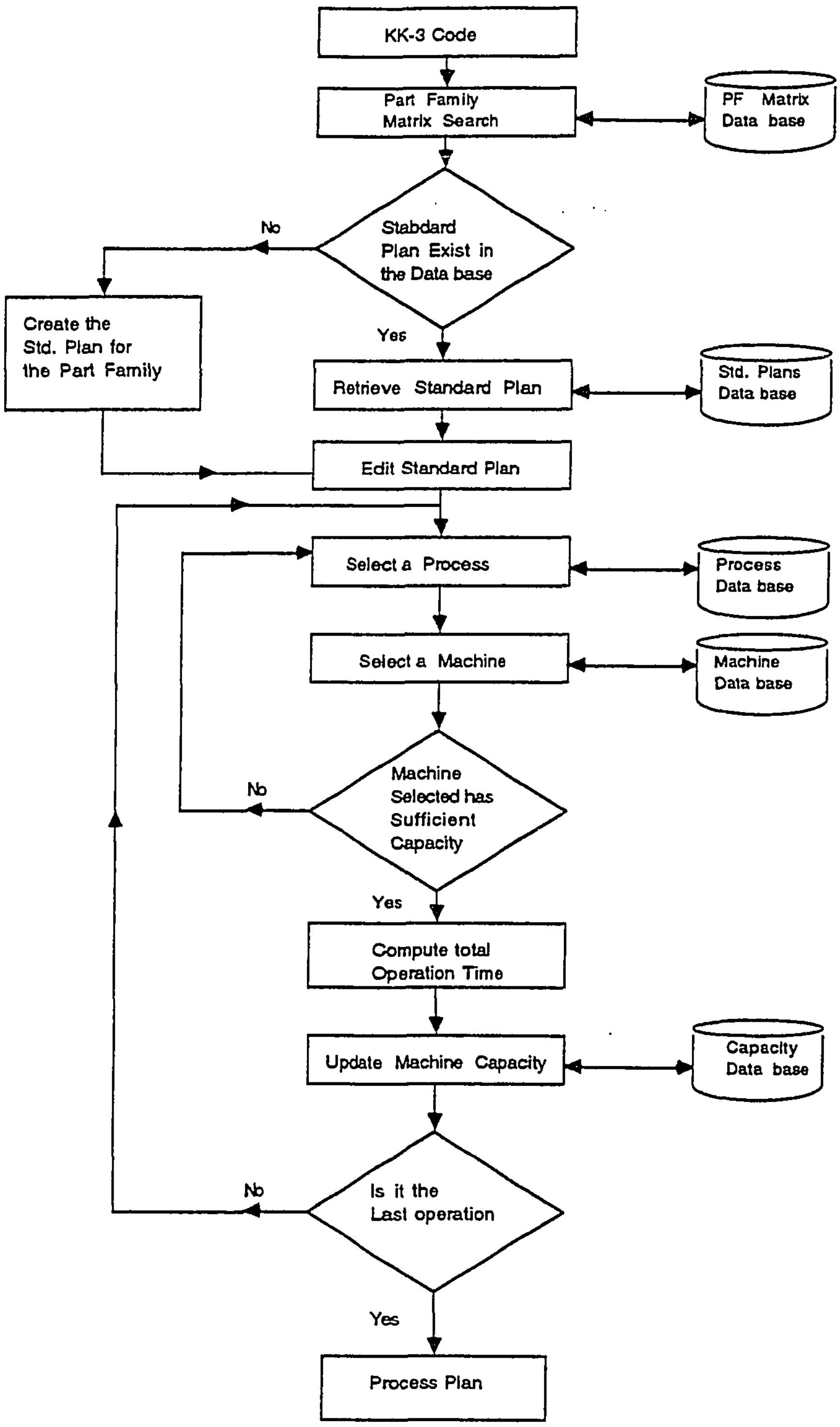

Figure 5. Flow Diagram of the Production Stage.

ACAPP with production planning functions the data structure has gained much more importance. Data files in A-CAPP include: (a) process data file, (b) machine data file, (c) capacity data files, and (d) standard plans data files.

Process Data File

Any process can be performed on a variable number of machine categories. The process data consist of various machine categories on which each process can be performed. These process data are stored in A-CAPP system data base in altmc.dat file. Each record in altmc.dat consists of three fields. The first field contains the name of the operation. The second field contains the number of alternate machine categories, and the third field contains the alternate machine categories. The structure of this altmc.dat is shown in Table 2. The third field is of variable length, the exact length of which is determined by the second field.

Machine Data File

On any shop floor there will be a variety of machines for each machine category. The machine data base consists of various machines of each machine category. In the A-CAPP system these machine data are stored in mac.dat file. Each record in this file consists of three fields. The

Table 2

Process Data: Alternate Machine Categories

Process	Number of alternate categories	Alternate machine categories
Turning	3	Lathe Boring mill Vertical shaper
Facing	2	Lathe Boring mill
Milling	2	Milling machine Lathe with special attachment
Shaping	2	Horizontal shaper Vertical shaper
Planing	1	Planer
Drilling	3	Drill press Lathe Milling machine
Boring	4	Lathe Boring mill Milling machine Drill press

three fields store machine category, number of machines, and the various machines of the machine category respectively. The structure of this file is shown in Table 3. The third field in this file is also of variable length.

Table 3

Machine Data: Various Machines of Each Machine Category

Machine category	Number of machines	Machines
Lathe	3	L111, L112, L113
Grinders	2	G161, G162
Boring Machines	1	B131
Drill Press	1	D171
Milling Machines	2	M141, M142
Planer	1	P151
Horizontal Shaper	2	S161, S162
Vertical Shaper	1	S127

Capacity Data Files

In the A-CAPP system there are two different capacity data files. They are (1) actual or initial capacity file and (2) available capacity file. Actual or initial capacity means maximum capacity of the shop floor. In other words, it is the capacity of the shop floor at the beginning of any planning horizon. These initial capacity data are stored in the A-CAPP system in acap.dat file. The structure of the acap.dat file is shown in Table 4. This

Table 4

Initial Capacity Data

Machine	Scheduled Capacity	Available capacity
L111	0	200
L112	0	200
L113	0	200
G161	0	200
G162	0	200
B131	0	200
D171	0	200
M141	0	200
M142	0	200
P151	0	200
S121	0	200
S122	0	200
S127	0	200
B181	0	200

file contains records of fixed length. Available capacity means the actual capacity yet to be scheduled. These available capacity data are stored in the A-CAPP system in cap.dat file. The structure of cap.dat file is shown in Table 5. This file contains records of fixed length. This file is updated by the system each time a machine is selected for an operation.

Standard Plans Data Files

In A-CAPP, there are two types of standard plans data base. The first data file std.dat consists of two fields per record of data. The first field contains part family code, while the second field contains the name of the file in which the standard plan for the part family is stored. The structure of this data file is shown in Table 6. The second data base consists of the standard plans for the part family. The structure of a standard plan is shown in Table 7. Table 8 shows the structure of a process plan.

A-CAPP System Description

In A-CAPP, machining operations like turning, drilling, facing, boring, grinding, shaping, planing, and milling are well supported. To meet the requirements of these operations, a set of 25 machines consisting of varieties of lathe, drilling, planing, milling, shaping, and

Table 5

Available Capacity Data

Machine	Scheduled capacity	Available capacity
L111	40	160
L112	31	169
L113	0	200
G161	29	171
G162	10	190
B131	27	173
D171	36	164
M141	60	140
M142	33	167
P151	51	149
S121	29	171
S122	20	180
S127	0	200
B181	30	170

Table 6

Standard Plans Data

Family code	Name of the file in which standard plan is stored
111111	SP1
112211	SP3
112112	SP4
121112	SP7
121111	SP6
111121	SP9

Table 7

Structure of a Standard Plan

S. NO.	Operation number	Number of alternate processes	Alternate processes
1	10	2	Turning, Facing
2	20	2	Shaping, Planing
3	30	1	Grinding

Table 8

Structure of a Process Plan

Part Name: Cam shaft	Production Volume: 200
Part reference number: S12345	Drawing Number: D23451
Planner: Rao Gali	Date: 05/11/1991

Operation number	Operation description	Machine code	Hours required	Special remarks
10	Turning	L111	2.136	
20	Milling	M141	1.654	
30	Shaping	S121	2	
40	Boring	B151	2.765	
50	Grinding	G161	1.789	

grinding machines is chosen.

As stated earlier in this chapter, the A-CAPP system has a modular structure. The major modules of the A-CAPP system are: (a) coding, (b) family formation, (b) standard plans generation, (d) editing of the standard plans, (e) process selection, (f) machine selection, and (g) capacity. A-CAPP system design and working is described here in terms of the important aspects of these modules.

Coding

In A-CAPP, parts are classified using 21-digit KK-3 code. General structure of the KK-3 code for rotational parts is shown earlier in Table 1.

Family Formation

In A-CAPP, parts are classified into part families based on the following six vital features of the parts: (1) external primary surface (this feature is represented in the KK-3 code by the eighth digit), (2) external concentric screw thread (represented in the KK-3 code by the ninth digit), (3) external shaped surface (represented in the KK-3 code by the eleventh digit), (4) internal primary shape (represented in the KK-3 code by the fourteenth digit), (5) internal flat surface (represented in the KK-3 code by the sixteenth digit), and (6) end surface (represented in the KK-3 code by the sixteenth digit).

Each of these six features is further divided into two categories based on the complexity of the feature. Of these two categories, the simple category is represented by number 1 and the complex category is represented by number 2. So, the part family code consists of six digits with each digit taking the value of either 1 or 2. Examples of some part family codes are 111111, 111211, 111112, 121112, and so on. According to this part family coding scheme, the total number of part families is equal to $2^6 = 64$, so any part belongs to one of these 64 families.

The family search module searches for the family to which a part belongs. Once it identifies the part family, then it determines whether a standard plan for the family exists in the data base or not. If the standard plan exists, then the system gives the following message to the process planner.

> Standard plan for the family to which this part belongs already exists in the data base. Hit any key to retrieve it.

If the standard plan is not there in the data base, then the system gives the following message to the process planner.

> Standard plan for the family to which this part belongs is not there in the data base. Hit any key to create the standard plan for this part family.

If the standard plan is not there in the data base, then the system asks the process planner to create the standard plan for this part family. The user can create the standard plan in the A-CAPP environment itself. At the time of creating the standard plan, the system helps the user through asking the user to provide the necessary information.

Editing

A-CAPP has several basic editing features. If the standard plan already exists in the data base, then the system retrieves the standard plan from the data base. Since this standard plan may not be exactly what is required for the part at hand, editing of the standard plan has to be done. In A-CAPP, this modification of the standard plan to suit a particular part is carried out in the editing module. The two options available in the editing module are: (1) adding an operation and (2) deleting an operation. For adding an operation between two operations the process planner would enter an integer number which falls between the operation numbers of the two operations between which this operation has to be inserted. For example, if the user wants to insert an operation between two operations with operation numbers 10 and 20, then the planner would enter any integer greater than 10 and less than 20 as the operation number of the operation to be added. Then the system asks the planner to enter the number of alternative processes and the names of the alternative processes. If the planner wants to delete an operation, then he/she would simply enter the operation number of the operation to be deleted. In this way, A-CAPP system has the ability to edit the standard plans interactively. Once editing is done then the next step is the selection of processes and machines.

Process Selection, Machine Selection and Capacity Match

In the A-CAPP system, process selection module, machine selection module, and capacity search module work together. Hence, the working of these three modules is described together.

As soon as the editing of the standard plan is completed, the next stage in the process plan creation is the process selection based on the machine availability. First of all, the process selection module activates the capacity module which asks the process planner whether he wants to start with the initial capacities or with the updated capacities. Initial capacity means capacity of the machines in the shop floor at the beginning of the production cycle. Current or updated capacity refers to the remaining capacity of the machines at that instant (Current capacity = Initial capacity-Total allocated capacity). In the initial capacity option, the capacity of all the machines in the shop floor is changed to the original capacities for the production period. In this option, allocation of machine hours required for each operation is accounted against the initial capacity of each machine. In the current capacity option, the allocation of machine hours required for each operation is accounted against the current available capacity on each machine.

If the process planner is generating process plans for parts to be produced in a new planning horizon, then he/she would choose the initial capacity option. But if he/she wants to generate process plans for current planning horizon, then he/she would choose the updated capacity option. Hence, process plans are always generated in A-CAPP based on the shop floor conditions. Furthermore, since any manufacturing facility produces more than one part, through using these two capacity options of A-CAPP, the process planner can find the combination/combinations of plans which will be best suited to any product mix at a particular time.

Once a capacity option is chosen, the system updates the capacity of all the machines. For each operation in the detailed plan, the system displays on the screen the alternative processes, and the various machines which can perform this operation along with their available capacities. Then the process planner would select one process and a machine. Once the planner has selected a machine, the system finds whether the selected machine has enough capacity to carry out that operation or not. If it does not have sufficient capacity, then the system informs the planner that the machine selected does not have sufficient capacity, and asks the planner to select another machine. If the process planner has selected a machine which has sufficient capacity, then the system updates the capacity of that machine. This procedure is carried out until processes and machines are selected for all the operations. At the end, the system prompts to enter the name of the file in which this plan is to be stored. The process plan just created can be viewed on the screen.

CHAPTER V

CONCLUSIONS AND SCOPE FOR FURTHER RESEARCH

Conclusions

It has been the objective of many researchers to create a totally automated manufacturing system, through integrating CAD, CAPP and CAM. A significant amount of research has been conducted in the areas of CAD, CAPP and CAM. However, the dream for a totally automated system is far from being realized. A major effort is still required in different areas in order to integrate the islands of automation (CAD and CAM). As mentioned earlier, process planning is the most important bridge between CAD and CAM. Several CAPP systems have been developed; however, all of them treat process planning as a static function, which means these systems always generate the process plans with the same process and machine combinations irrespective of the changes in the manufacturing environment. Hence, none of the existing CAPP systems is able to solve real-world problems.

In this research, the design and development of a CAPP system, which generates alternate process plans by interacting with production planning functions, have been presented. Through developing A-CAPP, this research demonstrated that it is feasible to develop a CAPP system, which responds to the changes in the manufacturing environment. Although this demonstrated system is limited to rotational machining parts, it presents an approach to integrating CAPP with scheduling, and it provides a tool to promote further integration. In other words, this research presents a prototype model of a large system that could be applied in a manufacturing company. Though the current system is limited to only rotational parts, it can be expanded quite easily due to the high modularity of the system.

Scope for Further Research

A-CAPP is by no means a complete automated process planning system. It is based on variant approach, which needs human knowledge in creating and editing standard plans. In Chapter II, difficulties associated with the development of a generative approach based process planning systems were discussed. Hence, future research should be focused to overcome those difficulties and develop a generative process planning system, which can generate alternate process plans.

One of the major challenges of CAD/CAM integration is to translate the CAD data base into a CAPP language. This requires a part feature recognition system, which is being pursued by many researchers. A general purpose part feature recognition system is required to enable the CAPP module to receive direct input of any desired workpiece. The A-CAPP system uses a group technology based, 21-digit KK-3 code as its input. This part coding is additional work, that can be eliminated through developing a CAPP system, which can extract the part features directly from a CAD data base.

As regards the integration of CAPP and scheduling, in the future the entire manufacturing environment can be simulated (as in the proposed methodology for integrating CAPP and FMS planning) so that the optimum feasible process plan for a planning horizon can be selected.

The capability of a CAPP system to generate alternative plans, as demonstrated in the A-CAPP system is an excellent capability, and its research for further development is extremely important especially for the success of the CAPP function in FMS technology.

Appendix

Example of a Process Plan Generation

Example of a Process Plan Generation

MENU

```
*******************************************
*                                         *
*    1    ENTER the part Code             *
*    2    Code the part                   *
*    3    Edit an existing Standard plan  *
*    4    RETURN to DOS                   *
*                                         *
*******************************************
```

ENTER 1/2/3/4 & hit RETURN ? 1

ENTER the 21-digit KK-3 Code and hit RETURN

```
  ---------------------
? 124134521221121111111
  ---------------------
```

```
************************************
*                                  *
*         The part code is         *
*       124134521221121111111      *
*                                  *
************************************


 Do you want to change the part code
    Enter 1 if yes  &  2 if not


            ? 2

     Enter production volume ? 200




     ENTER the part name
     ? XYZ

     Enter part reference number
     ? C215342

     Enter drawing number
     ? D78491

     Enter the name of the planner
     ? Rao Gali

     Enter to-day's date in the form mm/dd/year
     ? 07/22/1991
```

```
*****************************************
*                                       *
*   This part belongs to a Part Family  *
*   with code = 111111                  *
*                                       *
*****************************************

     Hit any key to continue
```

```
*******************************************
*                                         *
*   Standard plan for the family to which *
*   this part belongs is not there in the *
*   data base. So, you have to create the *
*   standard plan  for this  part family. *
*                                         *
*   Create the standard plan for this new *
*   part family and save it.              *
*                                         *
*******************************************

    Are you ready to create a new standard
          plan for this part family ?
           Enter  1  if yes
                  2  if you want to quit this

                     ? 1
```

```
ENTER the total number of operations
in the Standard Plan ? 5
```

```
ENTER the operation number of operation  1  ? 10

Enter no of alternative processes ? 2

Enter the name of alternative process  1  ? Facing

Enter the name of alternative process  2  ? Turning
```

```
ENTER the operation number of operation  2  ? 20
Enter no of alternative processes ? 2
Enter the name of alternative process  1  ? Turning
Enter the name of alternative process  2  ? Facing
```

```
ENTER the operation number of operation  3  ? 30
Enter no of alternative processes ? 3
Enter the name of alternative process  1  ? Milling
Enter the name of alternative process  2  ? Planing
Enter the name of alternative process  3  ? Shaping
```

```
ENTER the operation number of operation  4  ? 40
Enter no of alternative processes ? 1
Enter the name of alternative process  1  ? Boring
```

```
ENTER the operation number of operation  5  ? 50

Enter no of alternative processes ? 1

Enter the name of alternative process  1  ? Grinding
```

```
Enter the name of the file in which you
want to store this plan ? SP8
```

```
          Standard Plan

     ----------------------------
      1    10    2 Facing Turning
      2    20    2 Turning Facing
      3    30    3 Milling Planing Shaping
      4    40    1 Boring
      5    50    1 Grinding
     -----------------------------

     1    Edit the Standard Plan
     2    Go for Machine Search
     3    RETURN to the main Menu

     ENTER  1/2/3  &  hit RETURN ? 1
```

```
Do you need any help on Editing
  If yes enter 1 else enter 2


? 1

*****************HELP ON EDITING****************
*                                              *
*   In the process plan, first column contains *
*  the serial number of the Operation, second  *
*  column contains the operation number, third *
*  column contains the number of alternate     *
*  processes. While, the remaining columns     *
*  contains alternate processes.               *
*                                              *
*   If you want to add an Operation between    *
*  two operations, for example, let us say     *
*  between two operations with operation       *
*  numbers 10 and 20, then you have to enter   *
*  any integer greater than 10 and less than   *
*  20 as your Operation Number.                *
*                                              *
*   If you want to delete an Operation, then   *
*  you have to simply enter the Operation      *
*  number of the Operation to be deleted.      *
*                                              *
************************************************
         Hit any key to continue
```

Standard Plan

Serial number	Operation number	No of alter. processes	Alternative processes
1	10	2	Facing Turning
2	20	2	Turning Facing
3	30	3	Milling Planing Shaping
4	40	1	Boring
5	50	1	Grinding

```
        1    Add an operation
        2    Delete an operation
        3    Go for machine search

   Enter  1/2/3  &  hit  Return ? 3
```

Capacity Options Menu

```
******************************************
*                                        *
*   1   Start with Initial Capacities    *
*   2   Start with Updated Capacities    *
*   3   Help on these two options        *
*   4   Return to the main menu          *
*                                        *
******************************************

     ENTER 1/2/3/4 & hit RETURN ? 3
```

```
              HELP

*******************************************
*  Initial Capacity means the capacity of   *
*  the facility at the begining of the      *
*  production period. In otherwords it is   *
*  the total capacity of the facility.      *
*                                           *
*  Updated Capacity means the capacity of   *
* the facility at this time.                *
*                                           *
*  Updated Capacity = Initial Capacity -    *
*                     Scheduled Capacity    *
*                                           *
*******************************************

   Hit any key to continue
```

```
          Capacity Options Menu

****************************************
*                                      *
*   1   Start with Initial Capacities  *
*   2   Start with Updated Capacities  *
*   3   Help on these two options      *
*   4   Return to the main menu        *
*                                      *
****************************************

     ENTER 1/2/3/4 & hit RETURN ? 1
```

Process & Machine selection

```
 1     10    2          Facing     Turning

                  Facing

Lathe          L111    200     L112    200     L113    200
BorMc          B131    200

                  Turning

Lathe          L111    200     L112    200     L113    200
BorMc          B131    200
HShap          S121    200     S122    200

     Hit any key to continue

Enter the Process you have Selected ? fACING

Enter the Machine you have selected ? L111
```

```
 2     20    2          Turning    Facing

                  Turning

Lathe          L111    197     L112    200     L113    200
BorMc          B131    200
HShap          S121    200     S122    200
                  Facing

Lathe          L111    197     L112    200     L113    200
BorMc          B131    200

     Hit any key to continue

Enter the Process you have Selected ? Turning

Enter the Machine you have selected ? L111
```

```
 3    30   3         Milling    Planing    Shaping

                 Milling

MilMc        M141    200    M142    200
Lathe        L111    193.666L112    200    L113    200

                 Planing

Plane        P151    200


                 Shaping

HShap        S121    200    S122    200
VShap        S127    200

     Hit any key to continue

Enter the Process you have Selected ? Milling

Enter the Machine you have selected ? M141



 4    40   1         Boring

                 Boring

Lathe        L111    193.666L112    200    L113    200
BoMil        B181    200
MilMc        M141    195    M142    200

     Hit any key to continue

Enter the Process you have Selected ? Boring

Enter the Machine you have selected ? B181
```

```
 5     50    1          Grinding

                  Grinding

Grind          G161    200     G162    200
Lathe          L111    193.666L112    200     L113    200

     Hit any key to continue

Enter the Process you have Selected ? Grinding

Enter the Machine you have selected ? G161



Enter the name of the file in which you want
to store this process plan ? PP18
```

```
Do you want to view the process plan
         on the Screen ?

If yes ENTER 1  else  ENTER 2 ? 1
```

Process Plan

Part Name:	XYZ		
Part ref no:	C215342	Drawing no:	D78491
Planner:	Rao Gali	Date:	07/22/1991

Operation number	Operation	Machine	Time in hours	Special tools	Remarks column
10	fACING	L111	3		
20	Turning	L111	3.333		
30	Milling	M141	5		
40	Boring	B181	9		
50	Grinding	G161	1.666		

Hit any key to continue

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