Expert Process Planning for Manufacturing

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Purdue University

Addison-Wesley Publishing Company

Reading, Massachusetts • Menlo Park, California • New York
Don Mills, Ontario • Wokingham, England • Amsterdam
Bonn • Sydney • Singapore • Tokyo • Madrid • San Juan

Library of Congress Cataloging-in-Publication Data

Chang, Tien-Chien, 1954-
Expert Process Planning for Manufacturing / by Tien-Chien Chang.
p. cm.
Includes bibliographical references.
ISBN 0-201-18297-1
1. Production planning—Data processing. 2. Expert systems (Computer science) I. Title.
TS176.C452 1990
658.5'00285—dc20 89-18341
CIP

ABCDEFGHIJ-MA-943210

Preface

In the product realization process, the first and most important step is making a process plan. The quality of a product and the cost of producing it are strongly influenced by the process plan. Production planning, scheduling, part programming, facilities layout, etc.—all these functions take process plan as their input. In the past the majority of manufacturing systems were operated by humans. Since such a system responds slowly and is able to adapt to incomplete information, an inflexible and slow process plan generation mechanism is acceptable. Either manual process planning or retrieval-based variant process planning systems can satisfy the need. Today, the production method is gradually moving toward automation. Flexible automation has been especially stressed in recent years. The need for dynamic responses, fast plan generation, and smooth interface between design and manufacturing functions become essential in operating the new manufacturing systems. Thus, the automation of the planning function is critical.

Computer-Aided Process Planning (CAPP) or automated process planning is an approach that uses computers to generate a process plan. When constructed properly, such a system can satisfy the above mentioned needs. However, the task of automating the process planning function is not a simple one. No single algorithm can model the complexity of the thinking process of an experienced human planner. Thus, Artificial Intelligence (AI) seems to be a natural candidate for the application.

The development of CAPP started in the late sixties. The pioneers treated the process planning problem as a machining optimization problem. In the early seventies the Group Technology (GT) concept was introduced. Several GT-based retrieval systems were developed. *GT code, part family, standard process plan*, and *plan editing* were some terms familiar to users. Those systems by no means generated new process plans automatically. Yet, even the time and cost saved by using retrieval-based process planning systems pleased many users. Many of today's process planning systems are still of this type. This approach came to be called "variant" approach, since it varies the existing plan manually to make a new plan.

A system that can eliminate the manual editing work during process planning is desirable. In the mid-seventies the generative process planning approach was studied. Since then many other systems have been built. The majority of these systems either automate only a small portion of the overall process planning function or handle a very restricted domain of parts. Several such systems have been implemented in industry. All of them require certain degrees of human interaction. The eighties marks the beginning of AI in process planning. After years of frustration, a branch of AI—Expert System—finally paid off. Many successful implementations of expert system in industry have been reported. One of the fruitful application areas of expert system is in planning. The need in manufacturing process planning seems to match the expert system capability well. Many works have since been reported in the literature, yet few address the problem from an AI point of view and in an integrated manner.

The purpose of this book is to provide a complete, yet concise, introduction to expert process planning systems. Starting from the input or design representation, to the expert system formulation, every aspect of building process planning is discussed. Material collected from open literature and the research results developed by the author are arranged in a unified manner. This book also discusses research issues which need to be addressed. It can be used as a reference book for both researchers and industrial practitioners. This book can also be used as a textbook in a graduate level course on automated process planning. When complemented with reading assignments, it can cover a three-credit-hours course. Although not essential, knowledge about manufacturing processes, artificial intelligence, and computer programming will be helpful to readers. Other books published in this series can also be used to complement this book.

Since research in automated process planning has not reached its maturity, new developments occur at a rapid rate. It is not the author's intention to suggest that what is discussed in this book is the final word, or even the best approach. Rather, this book presents a summary of what has been done in the past decade in the field of automated process planning. The author hopes this book can provide new researchers guidance when they enter this interesting field, and can prevent redundant work being done.

As with any other book, the information has been collected from many sources. Much of the knowledge covered in this book is the result of the research work carried out by the author, his students, and colleagues. He especially would like to acknowledge the following: his former students Dr. Sanjay Joshi for his study on feature recognition, Mahesh Kanumury and Jatin Shah for their study on QTC process planning systems, James Moore for his work on cell control, and Professors Dave Anderson and O. Robert Mitchell for their cooperation in developing, respectively, the design and the vision inspection system for the QTC system. The QTC system is highlighted in Chapter 6 of this book as an example of an expert process planning system.

The author also would like to thank Mr. Chris Pochowicz for his editorial help. Many other individuals also contributed to the book in one way or another. I am grateful to the referees for their useful comments. The assistance and encouragement from series editors, Drs. David Dornfeld and Tony Woo are appreciated. Last but not the least, the author would like to thank Mr. Don Fowley, senior engineering editor at Addison-Wesley, for his patience and support throughout the project. It was a pleasure working with him.

The support from the Engineering Research Center at Purdue University, which was founded by the National Science Foundation, a National Science Foundation Presidential Young Investigator Award, and matching funds received from Rockwell International, Xerox Corporation, and Digital Equipment Corporation enabled the author to conduct the research which resulted in this book. Their kind support is deeply appreciated.

Contents

1

Introduction

This book discusses how to develop an expert process planning system. In a sense, a process plan can be considered a recipe. A recipe is "a set of instructions for making something from various ingredients."[1] Given a detailed recipe, a novice cook can usually prepare almost any meal. Of course, the quality of the meal still depends on the talents of the cook. Cooking is an art, and like all arts, a little magic "touch" is very important to the final result. A chef, then, is a master cook who normally does not require any written recipe. He or she knows how many ingredients to put into the dish, at what temperature to cook it, how long each step in the process takes, and just when to stir the food. Based on the chef's experience, a delicious dish can be prepared in no time at all. However, ordinary people, like most of us, are not as experienced. Without recipes, we are forced to order elaborate dishes from a restaurant. Who writes the recipes, then? Naturally, they are written by talented, experienced chefs. Knowing this, we can apply the same principles of the culinary art to manufacturing.

[1] The Merriam-Webster Dictionary, G. & C. Merriam Co., 1974.

We will limit the domain of manufacturing, however, to discrete part machining. In this kind of manufacturing environment, a master machinist, such as a tool maker, is equivalent to a master chef. Just tell him what you want, and he can make it for you, with or without a detailed design drawing. Such a master knows how to run many types of machine tools. He can see in his mind the necessary processes a part needs. However, an ordinary machinist is not as talented. Without a detailed design drawing and manufacturing instructions, the process plan or recipe of manufacturing, he cannot complete the job. This process plan helps the machinist to complete the job step by step. When the manufacturing job is done by a group of operators, a process plan is essential so that the manager can schedule the jobs. In modern manufacturing, automation is a trend. Automated machines are not intelligent at all; they can only follow instructions. In order to run an automated manufacturing system, a detailed process plan (recipe) is a must, and the person who prepares process plans, a process planner, must be experienced in many aspects of manufacturing.

1.1 The Need for Process Planning

In the restaurant industry, there are fast food restaurants and restaurants for formal dining. In the manufacturing industry, there is mass production and batch production. A fast food restaurant begins with a few proven recipes, e.g., Big Mac, Quarter Pounder, French Fries, etc. The kitchen is designed to mass produce these products (foods). The manager of the restaurant can literally take someone from the street and put him or her to work in a few hours. World travelers will tell you that the Big Mac ordered from the McDonalds in Peking tastes exactly the same as the one from the McDonalds in their U.S. hometown. In manufacturing, mass production, production line, or transfer line works the same way. The line is designed to follow a proven process plan. Less experienced machine operators can be used to man the line. Just as fast food restaurants do not change their recipes often, mass production process plans are often not changed. What is important for such an environment is knowing how to optimize the process plan and the line design, so the system can run efficiently.

In a formal dinner restaurant, meals are made to order. In a very good restaurant, there may be a large menu from which to choose. Special instructions can be given to the kitchen to "customize" a dish. Here especially, the chef must be experienced and talented in order to correctly prepare such customized orders. In small batch manufacturing, the environment is very similar to those in the restaurant industry; however, there are some differences. Usually experienced machinists are needed to produce small batch manufacturing. Since machined parts are much more complicated than food dishes, however, one machinist may not know how to run all the machines needed for the part. A job shop may be designed to group machines which perform the same type of machining process in the same department. A part is routed through the job shop, and necessary operations are performed on the part. A process plan defines this route. Since a large variety of parts are made in the shop and new part designs arrive continuously, new process plans need to be prepared all the time. In order to reduce the level of skill required of the operators, the process plan needs to be extremely detailed. The most judgment is exercised at the process planning level, not at the operator level.

From this example, we can see that a process plan is a recipe for making manufactured products. It is essential in running a modern manufacturing system. Process planning can be defined as *an act of preparing detailed processing documentation for the manufacture of a piece part or assembly*. Depending on the production environment, it can be very rough as shown in Fig. 1.1, or it can be detailed as shown in Fig. 1.2. This detailed processing documentation may include processes selected, operation parameters, process sequence, setups, fixturing methods, and/or device programs (such as NC part programs). An expert process planning system denotes a computer software system which does process planning by using expert knowledge. We can consider an expert process planning system a subset of Computer-Aided Process Planning (CAPP) systems. Such a system can replace the human process planner. What is discussed in this book is actually more restrictive than the title may imply. The process planning domain is limited to the part being machined. In this book, we try to show the necessary information for developing an expert process planning system. The past research in this area is also presented.

Route Sheet	by: T.C. Chang
Part No. S1243 Part Name: Mounting Bracket	
workstation	Time(min)
1. Mtl Rm	
2. Mill02	5
3. Drl01	4
4. Insp	1

Figure 1.1 A rough process plan

PROCESS PLAN					ACE Inc.
Part No. S0125-F Part Name: Housing Original: S.D. Smart Date: 1/1/89 Checked: C.S. Good Date: 2/1/89			Material: steel 4340Si Changes: ______ Date: ______ Approved: T.C. Chang Date: 2/14/89		
No.	Operation Description	Workstation	Setup	Tool	Time (Min)
10	Mill bottom surface1	MILL01	see attach#1 for illustration	Face mill 6 teeth/4" dia	3 setup 5 machining
20	Mill top surface	MILL01	see attach#1	Face mill 6 teeth/4" dia	2 setup 6 machining
30	Drill 4 holes	DRL02	set on surface1	twist drill 1/2" dia 2" long	2 setup 3 machining

Figure 1.2 A detailed process plan

1.2 What Is Process Planning?

Process planning, as defined by Chang & Wysk [1985], is the act of preparing detailed operation instructions to transform an engineering design to a final part. The detailed plan contains the route, processes, process parameters, machines, and tools required for production. However, when used in different industries and different shops, the process planning functions may involve several or all of the following activities:

- selection of machining operations
- sequencing of machining operations
- selection of cutting tools
- selection of machine tools
- determining setup requirements
- calculations of cutting parameters
- tool path planning and generation of NC part programs
- design of jigs and fixtures

The degree of detail incorporated into a typical process plan usually varies from industry to industry. It depends on the type of parts, production methods, and documentation needs. A process plan for a tool-room-type manufacturing environment typically relies on the experience of the machinist and does not have to be written in any great detail. In fact, the instructions, "mak as per part print," may even suffice. In the automobile industry and other typical ma production-type industries, the process planning activity is embodied in the hard automation (the transfer and flow lines used for manufacturing component parts and assembly). For metal-forming-type manufacturing activities such as forging, stamping, die casting, sand casting, injection moulding, etc., the process planning requirements are embedded directly into the design of the die/mold used, where most process planning activity is fairly simple. Of course, making the die for the forming activities is a one-of-a-kind operation. The job-shop-type of manufacturing environment usually requires the most detailed process plans since the design of tools, jigs, fixtures, and manufacturing sequence, etc., are dictated directly by the process plan.

In order to perform the process planning activities, a process planner must

be able to understand and analyze part requirements,

have extensive knowledge of machine tools, cutting tools and their capabilities,

understand the interactions between the part, manufacturing, quality, and cost,

possess analytical capabilities.

The process planning activity has traditionally been experience-based and has been performed manually. A problem facing modern industry is the current lack of a skilled labor force to produce machined parts as has been done in the past. Manual process planning also has other problems. Variability among the planner's judgment and experience can lead to differences in the perception of what constitutes the optimal or best method of production. This manifests itself in the fact that most industries have several different process plans for the same part, which leads to inconsistent plans and additional paperwork. To alleviate this problem, a computer-aided approach is taken. Development in computer-aided process planning attempts to free the process planner from the planning process. Computer-aided process planning can eliminate many of the decisions required during planning. It has the following advantages:

1. It reduces the demand on the skilled planner.
2. It reduces the process planning time.
3. It reduces both process planning and manufacturing cost.

4. It creates consistent plans.
5. It produces accurate plans.
6. It increases productivity.

1.3 Approaches to Computer-Aided Process Planning

There are three basic approaches to computer-aided process planning—variant, generative, and automatic. The variant approach uses computer terminology to retrieve plans for similar components using table look-up procedures. The process planner then edits the plan to create a "variant" to suit the specific requirements of the component being planned. Creation and modification of standard plans are the process planner's responsibility. The generative approach, however, is based on generating a plan for each component without referring to existing plans. Generative-type systems are systems that perform many of the functions in a generative manner. The remaining functions are performed with the use of humans in the planning loop. Automated systems, on the other hand, completely eliminate humans from the planning process. In this approach, the computer is used in all aspects, from interpreting the design data to generating the final cutting path. The following sections provide a discussion of each of the approaches.

1.3.1 Variant Process Planning

The variant approach to process planning was the first approach used to computerize planning techniques. It is based on the concept that similar parts will have similar process plans. The computer can be used as a tool to assist in identifying similar plans, retrieving them, and editing the plans to suit the requirements for specific parts.

In order to implement variant process planning, GT-based part coding and classification is used as a foundation. Individual parts are coded based upon several characteristics and attributes. Part families are created of parts having sufficiently common attributes to group them into a family. This family formation is determined by analyzing the codes of the part spectrum. A standard plan consisting of a process plan to manufacture the entire family is created and stored for each part family. The development of a variant process planning system has two stages: the preparatory stage and the production stage.

During the preparatory stage, existing components are coded, classified, and later grouped into families (Fig. 1.3). The part family formation can be performed in several ways. Families can be formed based on geometric shapes or on process similarities. Several methods can be used to form these groupings. A simple approach would be to

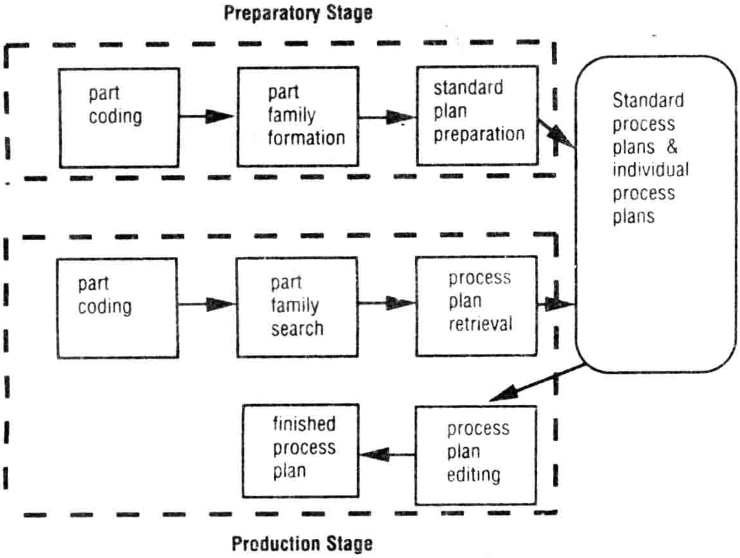

Figure 1.3 Variant process planning approach

compare the similarity of the part's code with other part codes. Since similar parts will have similar code characteristics, a logic which compares part of the code, or the entire code, can be used to determine similarity between parts.

Families can often be described by a set of family matrices. Each family has a binary matrix with a column for each digit in the code and a row for each value a code digit can have. A nonzero entry in the matrix indicates that the particular digit can have the value of that row, e.g., entry (3,2) equals one implies that a code x3xxx can be a member of the family. Since the processes of all family members are similar, a standard plan can be assigned to the family.

The standard plan is structured and stored in a coded manner using operation codes (OP-codes). An operation code represents a series of operations on one machine or workstation. For example, an OP-code DRL10 may represent the sequence center drill, change drill, drill hole, change to reamer, and ream hole. A series of OP-codes constitutes the representation of the standard process plan.

Before the system can be of any use, coding, classification, family formation, and standard plan preparation must be completed. The effectiveness and performance of the variant process planning system depends to a very large extent on the effort put forth at this stage. The preparatory stage is a very time consuming process.

The production stage occurs when the system is ready for production. New components can be planned in this stage. An incoming