南京航空航天大学
研究生系列精品教材

Integration of CAD/CAPP/CAM

CAD/CAPP/CAM集成技术

（英文版）

薛建彬　编著

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内 容 简 介

本书系统介绍了 CAD、CAPP 和 CAM 的基本概念，重点介绍了 CAD/CAPP/CAM 集成技术，并延伸至产品数据管理 PDM 和并行工程 CE。全书共分八章。第一章介绍了 CAD/CAPP/CAM 集成在产品全生命周期内的作用和地位，以及 CAD/CAPP/CAM 技术发展和 PDM、CE 之间的关系。第二章介绍了 CAD 技术的基础和三维模型的数学建模，并引入了逆向工程和 CAE 分析。第三章介绍了派生式、创成式 CAPP 的基本原理，并扩充到尺寸计算以及夹具设计等，还介绍了基于知识的 CAPP 系统的最新发展。第四章介绍了 CAM 技术的基础知识，包括 CNC 机床、CNC 系统、APT 语言，以及 CAD/CAM 集成系统，引入了 3D 打印技术。第五章介绍了 CAD/CAPP/CAM 集成，主要是 DXF、IGES、PDES、STEP 以及 STEP-NC 等中性文件的集成技术。第六章介绍了产品数据管理 PDM 系统、PDM 系统的功能模块及最新发展。第七章介绍了并行工程 CE，在 CAD/CAPP/CAM 集成的基础上，可以实现产品开发的并行工程，缩短产品开发周期，并介绍了常用的 DFA&M、数字化建模、项目管理等并行工程关键使能工具。第八章展望了 CAD/CAPP/CAM 集成技术的未来，介绍了当前流行的 CAD/CAM 软件的发展趋势。

本书适合作为机械工程类专业高年级本科生和硕士、博士研究生的双语教材，也可供相关专业人士参考。

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Preface

Overview

This textbook has been written to include the fundamental concepts on computer aided design (CAD), computer aided process planning (CAPP), computer aided manufacturing (CAM) and their integration in a generic framework. As we all know, with the development of computer science and technology, there are many commercial CAD/CAM software packages available in today's market, such as Solid Works, Pro/Engineer, Pro/Creo, CATIA, Master CAM, UG-NX, Auto CAD, and so on. Although the syntax of these systems differs from one another, their semantics are the same. So we just explain the principles of these systems in a generic and syntax independent fashion, and do not mention their syntax, so that students can use different systems with the same knowledge. The related mathematical developments and concepts to these systems are discussed to unravel the inside secrets.

This textbook is also designed to meet the demands of both practice-oriented and theoretically based courses. Students are required to master the knowledge of understanding three dimensional (3D) modeling and viewing, geometric modeling, product design, process planning, manufacturing, product data management, product life cycle management and concurrent engineering. Several widely used CAD/CAM systems are mentioned in the context. Some screen shots for using these systems are illustrated in some chapters. Students are encouraged to practice the knowledge by operating one of the mentioned software packages.

Audience

Students need a comprehensive and complete source of CAD/CAPP/CAM knowledge in order to become proficient in using any CAD/CAM systems. The professional engineers also need to know the knowledge. This textbook offers concentrated knowledge and explains the subject matter in a simple, yet comprehensive and coherent way. This textbook can help the users to get answers to specific questions they have while using CAD/CAM systems.

The audience of this textbook includes:

- The students in mechanical engineering, industrial engineering, manufacturing engineering and mechatronics engineering
- The instructors for CAD/CAPP/CAM courses
- The professional engineers

Organization

This textbook is divided into eight chapters. The first chapter is introduction. The principle concepts of CAD, CAPP and CAM are introduced. The development history of the systems is described. The integration of CAD/CAPP/CAM is also introduced. The following three chapters describe CAD, CAPP and CAM respectively. In Chapter 2, basic CAD knowledge is provided with 3D geometric modeling, common used CAD systems, and information inside the CAD systems. The edge-cutting technology about reverse engineering is also included in this chapter. In Chapter 3, the fundamental concepts of CAPP are presented. The variant and generative CAPP systems are introduced. Some well known CAPP systems are introduced. In Chapter 4, the computer numerical control (CNC) and CAM are discussed. The new concept of 3D printing is also introduced. After knowing these isolated automation islands, the efforts to integrate these systems are described in Chapter 5. Data exchange methods are listed. Several neural data formats, such as DXF, IGES, STEP and STEP-NC are discussed. With so many files generated from the systems, product data management (PDM) is required to deal with these files. In Chapter 6, the functions of product data management system are analyzed. Some famous PDM systems are introduced. Based on PDM, the integration of CAD/CAPP/CAM has got a new approach. The PDM concept is even extended to product life-cycle management (PLM). In Chapter 7, concurrent engineering is described to enhance the product development. The collaborative design and team work are emphasized in concurrent engineering design. In the last chapter, some future developments of CAD/CAPP/CAM are proposed.

This textbook is written in such a way that each chapter stands on its own, that is, the chapters need not be taught sequentially. So the chapters can be selected depending on the course's focus and philosophy.

Example of course syllabus

The original purpose of this book is to provide a textbook for the course of Integration of CAD/CAPP/CAM at postgraduate level at Nanjing University of Aeronautics and Astronautics. Here is the course syllabus that has been used for eight years. This can offer some reference for other courses at other levels or other majors.

Course Code：FE**0530009**

Course Title(Chinese)：CAD/CAPP/CAM **集成技术**

Course Title(English)：**Integration of CAD/CAPP/CAM**

College and department：Department of Mechanical and Electronical Engineering

Semester：2

Class hours：40

Teaching methods：Lecture and experiments

Suitable majors: Mechanical Engineering, Mechatronics Engineering
Assessment instruments: Mini-project and final examination
Pre-requisites: Computer aided design, Numerical control programming

Course Objective and Requirements

This course is developed to systematically deliver the principle knowledge about computer aided design (CAD), computer aided process planning (CAPP), computer aided manufacturing (CAM), product data management (PDM), and concurrent engineering (CE) to the students at post-graduate levels. The integration methods are studied by analyzing the exchanged information between these isolated systems. The product data model of STEP is one of the ideal solutions. The STEP model contains the information throughout the whole product life-cycle. PDM provides a platform for 3C systems integration. The contents of PDM are developing with the progress of 3C technology. Based on the integration of CAD/CAPP/CAM, the concept of CE is introduced, as well as the related theories and applications.

During this course, the students are required to master the basic principles of CAD, CAPP, CAM and PDM, be familiar with the commercial software packages. Students must know the integration theories and methods on CAD/CAPP/CAM. After taking this course, the abilities on logic thought will be enhanced, and the abilities on analyzing and solving problems will be improved. It is helpful for the students project research in the near future.

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Last but not least, very special thanks are due to my family members and friends who supported me from start to finish with their loves, supports and encouragements.

If you have any questions or comments about this textbook, please email to Jianbin Xue at meejbxue@nuaa.edu.cn.

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Contents

Chapter 1 Introduction

Questions before you read:

1. Do you know something about CAD, CAPP and CAM?
2. What is the whole product life cycle?
3. How do you plan to carry out product design and manufacture?
4. What kinds of software packages do you need in product design and manufacture?

The goal of this chapter is to understand the basic concept of integration of CAD/CAPP/CAM, their roles in the whole product life cycle, and the brief history of the isolated systems. The concepts of product data management (PDM) and concurrent engineering (CE) are also briefly introduced in this chapter.

1.1 Product design and manufacture

Do you ever want to design and manufacture a product? During your childhood, you must have been attracted by some amazing products. You want to make it. However, your knowledge was limited at that time. You admired the carpenters who could make a number of products of wood. You also admired the blacksmiths who could make tools of steel. And now there are a large number of plants making many products of different material every day. Do you have such an intention to find out how these products were made of? Here we will give you a general description about the product life cycle.

Product life cycle

In the field of economics, the product life cycle has been divided into four stages: introduction, growth, maturity and decline. But here in this textbook, the product life cycle means the product development life cycle, which is a complex procedure illustrated in Fig. 1-1. The product begins with a need based on customers demands. From the voice of customers, to market analysis, product design, process planning, manufacture, sales, use and discard. The first two blocks and the last two blocks are mostly related to markets, sales and services, which can be classified into the management field. The design, process planning and manufacture is closely related to mechanical engineering, so these three blocks can be classified into the engineering field. The main content of this textbook covers these three blocks: product design, process planning and product manufacture. With the development of computer science and technology, computers are used to help the engineers in different stages of product development. So computer aided design (CAD) is the automation of product design, computer aided process planning (CAPP) is the automation of process planning, and computer aided manufacturing (CAM) is the automation of product manufacture. This textbook will introduce the integration of CAD/CAPP/CAM. The interfaces between the product design, process planning and product manufacture will be described and analyzed.

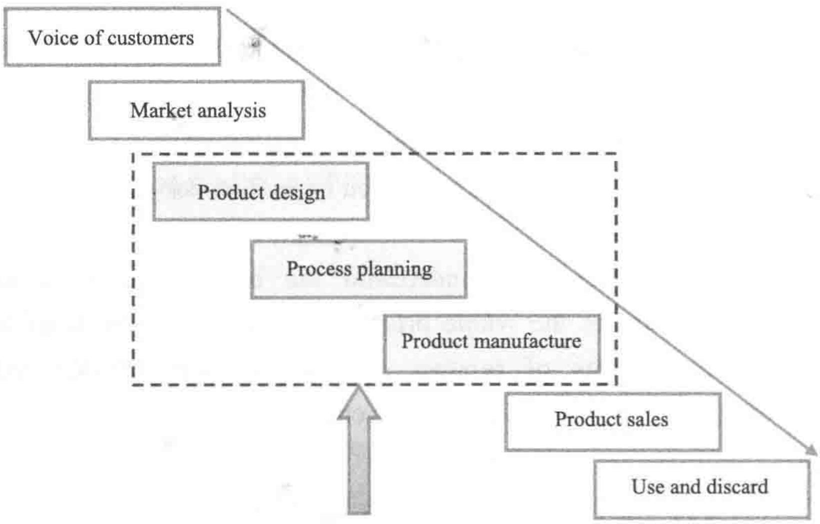

Fig. 1-1　Product life cycle

Basic concept of CAD/CAPP/CAM

The modern manufacturing environment can be characterized by the paradigm of delivering products of increasing variety, smaller lots and higher quality in the context of increasing global competition. Industrial companies cannot survive worldwide competition unless they introduce new products with better quality, at lower costs and with shorter lead-time. There is intense international competition and decreased availability of skilled labor. With dramatic changes in computing power and wider availability of software tools for design and production, engineers are now using Computer Aided Design (CAD), Computer Aided Process Planning (CAPP), Computer Aided Manufacturing (CAM) and Computer Aided Engineering (CAE) systems to automate their design and production processes. These technologies are now used everyday for engineering tasks. Below is a brief description that how CAD, CAPP, CAM, and CAE technologies are used during the product realization process.

The term CAD/CAPP/CAM is a shortening of integration of CAD, CAPP and CAM. CAD and CAM are two essential tools to design and manufacture parts. CAPP is trying to bridge the two systems by seamless integration. Recently years, the CAE becomes popular. And it must be also integrated with other CAX systems. So the integration of CAD/CAPP/CAM should be extended to be CAD/CAPP/CAM/CAE.

In each stage, there are several main tasks to be finished respectively. Fig. 1-2 shows the main tasks of the three stages.

In the stage of product design, CAD software packages are the main tool. CAD systems are used for geometric modeling, engineering analysis, simulation, scientific computing, graphics and engineering database. Reverse engineering is a new approach for product design. With the development of network, CAD is also used to communicate between different engineers from different departments.

In the stage of process planning, CAPP software packages are the main tools. CAPP systems help engineers carry out rough casting design, machining process selection, operation design, routing design, ration of man-hour, tooling, and fixture and jigs.

In the stage of product manufacture, CAM is the main tool. CAM systems are used for NC programming, tool path planning, cutting data files, simulation of tool path, NC code verification, check out and trial manufacture. 3D printing is a new method for product manufacture. It is a kind of additive manufacturing.

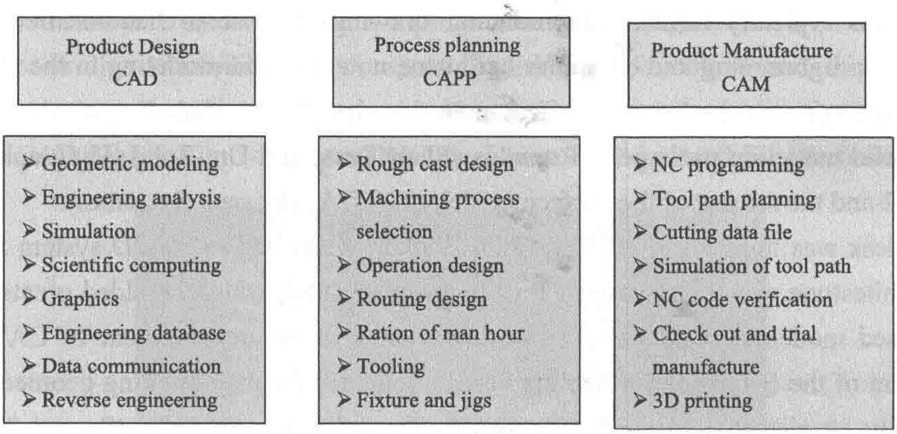

Fig. 1-2 Design, process planning and manufacture

Computer applications have been found in the entire spectrum of the product development process, ranging from conceptual design to product realization, and even recycling. CAD, CAPP and CAM could have been independent systems. They are now seamlessly integrated because most of the common information about products must be shared among them. So the main point is the integration which is expressed with the slashes. Here the slashes among the three or four CAx systems play more important roles in the development of products. They represent the integration relationships among these systems.

1.2 Development of CAD/CAPP/CAM

1.2.1 Computer aided design

CAD is mainly used for detailed engineering of 3D models and/or 2D drawings of physical components, but it is also used throughout the engineering process from conceptual design and layout of products, through strength and dynamic analysis of assemblies to definition of manufacturing methods of components.

Designers have long used computers for their calculations. Initial developments were carried out in the 1960's within the aircraft and automotive industries in the area of 3D surface construction and NC programming, most of it independent of one another and often not publicly published until much later.

First commercial applications of CAD were in large companies in the automotive and aerospace industries, as well as in electronics. Only large corporations could afford the computers capable of performing the calculations.

As computers became more affordable, the application areas have gradually expanded. The development of CAD software for personal desk-top computers was the impetus for almost universal application in all areas of construction.

CAD implementations have evolved dramatically since then. Initially, with 2D in the 1970s, it was typically limited to producing drawings similar to hand-drafted drawings. Advances in programming and computer hardware, notably solid modeling in the 1980s, have allowed more versatile applications of computers in design activities. Key products for 1981 were the solid modeling packages - Romulus (ShapeData) and Uni-Solid (Unigraphics) based on PADL-2 and the release of the surface modeler CATIA (Dassault Systemes).

Autodesk was founded in 1982 by John Walker, which led to the 2D system AutoCAD. The next milestone was the release of Pro/Engineer in 1988, which heralded greater usage of feature based modeling methods. Also of importance to the development of CAD was the development of the B-rep solid modeling kernels (engines for manipulating geometrically and topologically consistent 3D objects) Parasolid (Shape Data) and ACIS (Spatial Technology Inc.) at the end of the 1980s and the beginning of the 1990s, both inspired by the work of Ian Braid. This led to the release of mid-range packages such as Solid Works in 1995 Solid Edge (Intergraph) in 1996 and Iron CAD in 1998.

Starting the late 1980's, the development of readily affordable CAD programs that could be run on personal computers began a trend of massive downsizing in drafting departments in many small to mid-size companies. As a general rule, one CAD operator could readily replace at least four or five drafters using traditional methods. Additionally, many engineers began to do their own drafting work, further eliminating the need for traditional drafting departments. This trend mirrored that of the elimination of many office jobs traditionally performed by a secretary as word processors, spreadsheets, databases etc., became standard software packages that everyone was expected to learn.

Today CAD is not limited to drafting and rendering, and it ventures into many more "intellectual" areas of a designer's expertise. Computer aided design is used in many businesses and organizations around the world.

1.2.2 Computer-aided manufacturing

The field of computer-aided design has steadily advanced over the past five decades to the stage at which conceptual designs for new products can be made entirely within the framework of CAD software. From the development of the basic design to the bill of materials necessary to manufacture the product there is no requirement in any stage of the process to build physical prototypes.

Computer-aided manufacturing takes this one step further by bridging the gap between the conceptual design and the manufacturing of the finished product. Whereas in the past it would be necessary for design developed using CAD software to be manually converted into a drafted paper drawing detailing instructions for its manufacture, computer-aided manufacturing software allows data from CAD software to be converted directly into a set of manufacturing instructions.

CAM software converts 3D models generated in CAD into a set of basic operating instructions written in G-code. G-code is a programming language that can be understood by numerical controlled machine tools – essentially industrial robots – and the G-code can instruct the machine tool to manufacture a large number of items with perfect precision and faith to the CAD design. Fig. 1-3 shows CNC machine tool understand G-code from CAM.

Fig. 1-3 CNC machine tool understand G-code from CAM

Modern numerical controlled machine tools can be linked into a "cell", a collection of tools that each performs a specified task in the manufacture of a product. The product is passed along the cell in the manner of a production line, with each machine tool (i.e. welding and milling machines, drills, lathes etc.) performing a single step of the process.

For the sake of convenience, a single computer "controller" can drive all of the tools in a single cell. G-code instructions can be fed to this controller and then left to run the cell with minimal input from human supervisors. This may be called as direct numerical control (DNC).

Benefits of computer-aided manufacturing

While undesirable for factory workers, the ideal state of affairs for manufacturers is an entirely automated manufacturing process. In conjunction with computer-aided design, computer-aided manufacturing enables manufacturers to reduce the costs of producing goods by minimizing the involvement of human operators.

In addition to lower running costs there are several additional benefits to using CAM software. By removing the need to translate CAD models into manufacturing instructions through paper drafts it enables manufactures to make quick alterations to the product design, feeding updated instructions to the machine tools and seeing instant results.

In addition, many CAM software packages have the ability to manage simple tasks such as the re-ordering of parts, further minimizing human involvement. Though all numerical controlled machine tools have the ability to sense errors and automatically shut down, many can actually send a message to their human operators via mobile phones or e-mail, informing them of the problem and awaiting further instructions.

All in all, CAM software represents a continuation of the trend to make manufacturing entirely automated. While CAD removes the need to retain a team of drafters to design new products, CAM removes the need for skilled and unskilled factory workers. All of these developments result in lower operational costs, lower end product prices and increased profits for manufacturers.

Problems with computer-aided manufacturing

Unfortunately, there are several limitations of computer-aided manufacturing. Obviously, setting up the infrastructure to begin with can be extremely expensive. Computer-aided manufacturing requires not only the numerical controlled machine tools themselves but also an extensive suite of CAD/CAM software and hardware to develop the design models and convert them into manufacturing instructions – as well as trained operatives to run them.

Additionally, the field of computer-aided management is fraught with inconsistency. While all numerical controlled machine tools operate using G-code, there is no universally used standard for the code itself. Since there is such a wide variety of machine tools that use the code, it tends to be the case that manufacturers create their own bespoke codes, to operate their machinery.

While this lack of standardization may not be a problem in itself, it can become a problem when the time comes to convert 3D CAD designs into G-code. CAD systems tend to store data in their own proprietary format (in the same way that word processor applications do), so it can often be a challenge to transfer data from CAD to CAM software and then into whatever form of G-code the manufacturer employs.

Well before the development of computer-aided design, the manufacturing world adopted tools controlled by numbers and letters to fill the need for manufacturing complex shapes in an accurate and repeatable manner. During the 1950's these Numerically-Controlled machines used the existing technology of paper tapes with regularly spaced holes punched in them to feed numbers into controller machines that were wired to the motors positioning the work on machine tools. The electro-mechanical nature of the controllers allowed digital technologies to be easily incorporated as they were developed.

By the late 1960's numerically-controlled machining centers were commercially available, incorporating a variety of machining processes and automatic tool changing. Such tools were capable of doing work on multiple surfaces of a work-piece, moving the work-piece to positions programmed in advance and using a variety of tools—all automatically. What is more, the same work could be done over and over again with extraordinary precision and very little additional human input. NC tools immediately raised automation of manufacturing to a new level once feedback loops were incorporated (the tool tells the computer where it is, while the computer tells it where it should be).

What finally made NC technology enormously successful was the development of the universal NC programming language called APT (Automatically Programmed Tools). Announced at MIT in 1962, APT allowed programmers to develop post processors specific to each type of NC tool so that the output from the APT program could be shared among different parties with different manufacturing capabilities.

1.2.3 CAD & CAM together

The development of computer-aided design had little effect on CNC initially due to the different capabilities and file formats used by drawing and machining programs. However, as CAD applications such as Solid Works and Auto CAD incorporate CAM intelligence, and as CAM applications such as Master CAM adopt sophisticated CAD tools, both designers and manufacturers are now enjoying an increasing variety of capable CAD/CAM software. Most CAD/CAM software was developed for product development and the design and manufacturing of components and molds, but they are being used by architects with greater frequency.

Today, over three-quarters of new machine tools incorporate CNC technologies. These tools are used in every conceivable manufacturing sector, including many that affect building technologies. CNC technology is related to Computer Integrated Manufacturing (CIM), Computer Aided Process Planning (CAPP) and other technologies such as Group Technology (GT) and Cellular Manufacturing. Flexible Manufacturing Systems (FMS) and Just-In-Time Production (JIT) are made possible by Numerically-Controlled Machines.

1.2.4 Computer aided process planning

Unlike computer aided design (CAD) and computer aided manufacturing (CAM) systems which have been used in industry for a long time, computer aided process planning (CAPP) systems are yet to be transferred from research laboratories to industry. Aircraft industries are trying to improve their performance by developing CAPP software. Aircraft parts are specific mainly because of their complex geometry, which generates many accessibility problems, and their thin shells, which generate machining deformation and vibration problems. New CAPP approaches have been specified and developed for aircraft structural parts. Machining features are defined as machining faces. The part is split up into a set of machining faces with accessibility, adjacency and rigidity properties. New set-up strategies are defined. These highlight three particular features in the machining of such parts: the categorization, which is a strict guide as to how the part should be machined; the best-fit blank orientation relative to the part; and the potential machining directions of the part which are the main elements for decision making.

1.3 Product data management

Traditional engineering design created product drawings and schematics on paper and using CAD tools to create parts lists. These engineering data must be managed with certain tools.

Product data management (PDM) manages engineering data - all the data related to a product and to the processes used to design, manufacture and support the product. Much of this data will be created with computer-based systems such as CAD, CAM and CAE. PDM systems also manage the flow of work through those activities that create or use engineering data. They support techniques, such as concurrent engineering, that aim to improve engineering workflow.

There are now computer systems on the market that help improve the flow, quality and use of engineering information throughout a company. These systems provide improved management of the engineering process through better control of engineering data, of engineering activities, of engineering changes and of product configurations.

1.4 Concurrent engineering

Concurrent engineering is a business strategy which replaces the traditional product development process with one in which tasks are done in parallel and there is an early consideration for every aspect of a product's development process. This strategy focuses on the optimization and distribution of a firm's resources in the design and development process to ensure an effective and efficient product development process. It mandates major changes within the organizations and firms that use it, due to the people and process integration requirements. Collaboration is a must for individuals, groups, departments and separate organizations within the firm. Therefore, it cannot be applied at leisure. A firm must be dedicated to the long term implementation, appraisal and continuous revision of a concurrent engineering process.

In this textbook, we cover the basics of CAD, CAPP, CAM, PDM and CE. Students should realize that each of the topics deserves a separate book by itself, and they should refer to existing books for further information.

1.5 Extending Integration of CAD/CAPP/CAM

Since the business of product development and manufacturing goes beyond activities of design, process planning and manufacture, integration will not stop at CAD/CAPP/CAM. The integration of CAD/CAPP/CAM system may be extended in various aspects.

Inspection, for example, is a logic step after CNC machining. Closed loop machining can not be realized without inspection. The dimensional inspection data model is specified in ISO 10303 AP219.

A CAD system is a combination of hardware and software that enables engineers and architects to design everything from furniture to airplanes. It allows an engineer to view a design from any angle with the push of a button and to zoom in or out for close-ups and long-distance views. In addition, the computer keeps track of design dependencies so that when the engineer changes one value, all other values that depend on it are automatically changed accordingly.

CAM system is a type of computer application that helps automate a factory. All these systems are concerned with automatically directing the manufacture and inventory of parts.

A frequently overlooked step in the integration of CAD/CAM is the process planning that must occur. CAD systems generate graphically oriented data and may go so far as graphically identifying metal, etc. to be removed during processing. In order to produce such things as NC instructions for CAM equipment, basic decisions regarding equipment to be used, tooling and operation sequence need to be made. This is the function of CAPP. Without some elements of CAPP, there would not be such a thing as CAD/CAM integration. Thus CAD/CAM systems that generate tool paths and NC programs include limited CAPP capabilities or imply a certain approach to processing.

CAD systems also provide graphically-oriented data to CAPP systems to use to produce assembly drawings, etc. Further, this graphically-oriented data can then be provided to manufacturing in the form of hardcopy drawings or work instruction displays. This type of system uses work instruction displays at factory workstations to display process plans