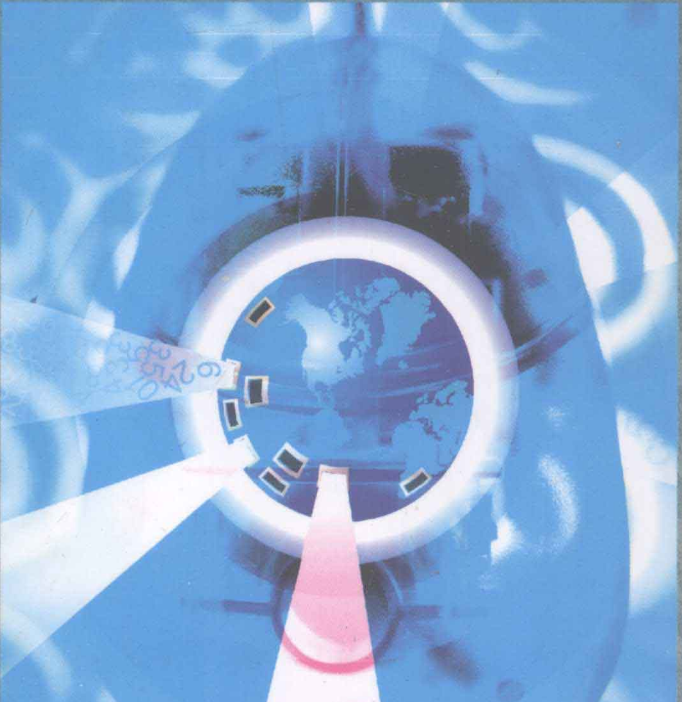
Special English

COMPUTER AIDED DESIGN



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Preface

The twenty-first century business environment will be characterized by expanding global competition and an increasing variety of products with low demand. In the coming years, we are going to witness an era of mass customization of products. To survive in such a competitive environment, not only do we have to evolve efficient manufacturing processes and technologies, we also have to bring people into the picture. People have to be trained in the latest technologies and processes in the areas of design.

The objective of this book is to provide up-to-date coverage of topics in computer aided design. In this book, Chapter 1 gives introduction to computer integrated design and manufacturing system. We provide an understanding of the design process in Chapter 2. The basic architecture of a computer aided design system is presented. This provides links among the CAD model database, input-output devices, device drivers, graphics utilities, application software, and the user interface. Various types of CAD/CAM systems, such as mainframe-, minicomputer-, workstation-, and microcomputer-based systems are described.

In Chapter 3 we provide a comprehensive coverage of various geometric modeling approaches wireframe, surface, and solid modeling. Parametric and variational design concepts and computer aided engineering analysis are also discussed. Chapter 4 gives detailed discussions of current topics such as concurrent engineering. SolidWorks 2000 is mechanical design automation software that takes advantage of the familiar Microsoft Windows graphical user interface. Some basic concepts and terminology used throughout the SolidWorks 2000 application are discussed.

The subject is covered by example in Chapter 6 to show how the computer frees the designer from burdensome computations and allows several "what if" questions to be answered quickly. Chapter 7 gives an elementary introduction to the increasingly important topics of case selector and rule based systems.

One of the oldest topics, computer assisted drafting, is surveyed in Chapter 8. Its use continues to increase, but the main concern here is how it best integrates with the above topics. There are important topics not included here. Surveys show that engineers may spend 20 percent of their time designing, and up to 80 percent of their time in preparing reports, communications, cost estimates, and so on. Thus, another important activity for engineers is to learn to use effectively spreadsheets, database management software, and word processing tools. Then they can increase productivity and enjoyment by spending a larger percentage of their time on the design process.

The book provides a quantitative analysis of computer aided design. Accordingly, a large number of solved examples are included to illustrate the concepts presented. The latest references and a good number of problems are included at the end of each chapter. A solution manual is available to instructors and can be obtained from the publisher. The book has gone through thorough classroom testing in several courses. During this process, a large number of students have contributed to the book in many ways. It is available, at an extra cost, from the publisher, which requires understanding of all the technologies and processes discussed in Chapters 2 through 9.

The text is directed toward senior undergraduate students from the department of industrial, manufacturing, and mechanical engineering, as well as corresponding graduate programs in Engineering Technology. This book will also be useful to practicing engineers and managers from a variety of fields who wish to understand modern engineering design and manufacturing concepts through solved examples and illustrations. This book was compiled by Liu Yongxian, Sui Tianzhong, Sheng Zhongqi, Li Dongsheng, Yang Ying, Wang Rende, Zhang Ruijin, etc.

Contents

1 INTRODUCTION

1.1 An Overview of a Manufacturing Enterprise

For most enterprises, the long-term goal is to stay in business, grow, and make a profit. This is particularly true of manufacturing enterprises, which must understand the dynamic changes that are taking place in the business environment. The twenty-first century business environment can be characterized by expanding global competition and products of increasing variety and lower demand. The globalization of economic activity has brought about a sea change in the attitudes of customers. Customer individualism is certain to become the central theme of business. What we are going to witness is an era of mass customization. This means manufacturing products for the mass market in such a way that products are customized for each individual in that market. Recall that in the 1970s, the cost of products was the main lever for obtaining competitive advantage. Later in the 1980s, quality superseded cost and became an important competitive dimension. Now low unit cost and high quality of products no longer solely define competitive advantage. Today, the customer takes both minimum cost and high quality for granted. Factors such as delivery performance and customization and environmental issues such as waste generation are assuming a predominant role in defining the success of organizations in terms of increased market share and profitability. The question is, what can we do under these changing circumstances to stay in business and retain competitive advantages?

As a first step what is needed is the development of the right business strategy to meet the challenges of present and future markets. In doing so, a manufacturing organization has not only to understand what customers want but also to develop internal mechanisms to respond instantly to the changes demanded by customers. This requires a paradigm shift in everything our factories do. They must not only make use of state-of-the-art technologies and concepts but also think in the reverse direction. "Reverse direction" means building products that realize customer expectations. That is, when an organization is deciding about business plans, it has to address several questions. Will the customer find any change in what one does as a result of using this? Will the customer be able to define any benefit? From the customer's point of view, a company has to respond to smaller and smaller market niches quickly with standardized products that will be built in lower and lower volume. In other words, we can say that a future successful manufacturing organization will be a virtual corporation that is instantaneously responsive to customer needs. This view has been shared by an industry-led consortium on twenty-first century manufacturing enterprise strategy.

The next step is to determine the right kind of resources to support the business strategy. This requires the right choice of people, technology, and business processes. What is further needed is a marriage of corporate strategies, technology, people, and business processes with a view to evolving policies so that all the functional organs of an organization (finance, sales and marketing, product engineering, manufacturing, and human resources) work in a synchronized manner to achieve corporate objectives. The obvious question then is, how should a manufacturing enterprise work?

We know that all the functional organs of a manufacturing enterprise, such as finance, sales and marketing, design and manufacturing, and human resources, continually receive feedback about products, product attributes, and market segments. Figure 1. 1 shows how customers play a pivotal role in defining the manufacturing enterprise. Corporate objectives such as growth in market share, profitability, work force stability, and other financial measures essentially emanate from the understanding of the marketplace. For example, marketing identifies a range of products, product market segments, and new product ideas to satisfy customer needs. Can a company deliver the kinds of products needed to satisfy order-winning criteria such as cost, quality, lead time, and so on? The answer to this question lies with design and manufacturing, which explore various product design and manufacturing process options as well as assess infrastructure to see if they can satisfy the order-winning criteria. Obviously, the human resources, technology, finance, and business processes in the company play a major role in answering this question and their interaction with manufacturing is very important. Accordingly, the manufacturing strategy should evolve from collaborative decision making that satisfies the requirements of finance, sales and marketing, design and manufacturing, and human resources. Collaborative decision making is a way to achieve congruence between the corporate objectives, marketing goals, and manufacturing capabilities of a manufacturing enterprise. This process may lead to revised corporate objectives and marketing goals. What eventually emerges from this process will be an implementable product design and manufacturing plan. This plan will satisfy order-winning criteria considering the requirements of business segments represented by marketing, finance, strategic planning, human resources, and manufacturing management. A design and manufacturing plan is built considering such aspects as product and process definition, manufacturing planning and control, and factory automation. Integration of a complete enterprise would facilitate successful implementation of these plans in realizing the corporate goals. Information resource management, communications, and a common database are required for the integration of a complete enterprise.

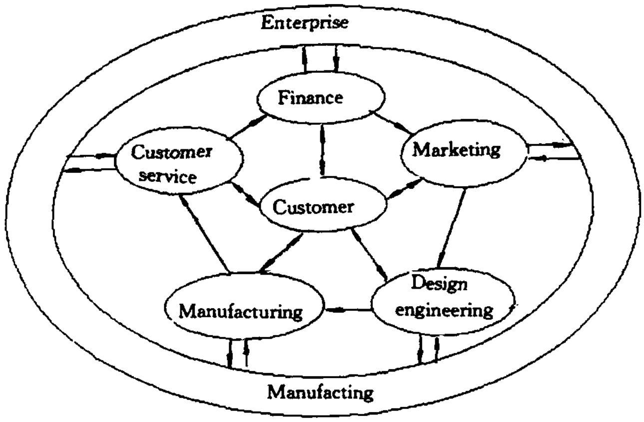

Figure 1.1 Customer and manufacturing enterprise

As discussed earlier in this section, mass customization with high delivery performance, high quality, low cost, and environmentally conscious products is required for a manufacturing organization to remain successful in the twenty-first century. To support such a virtual organization for discrete products manufacturing, a thorough understanding of the concepts and technologies for the design and manufacturing of products is necessary. Although the understanding of functional areas such as marketing, finance, and personnel is also important for the successful operation of a manufacturing enterprise, the scope of this book is limited to two major functional areas: design and manufacturing. Accordingly, this book provides a systems approach to understanding the concepts and technologies in computer integrated design and manufacturing systems. In later chapters we will discuss computer aided design (CAD), concurrent engineering (CE), computer aided process planning (CAPP), computer aided manufacturing (CAM), quality engineering, automated material handling, robotics, manufacturing planning and control, cellular manufacturing, just-in-time manufacturing (JIT), flexible manufacturing systems (FMSs), and enterprise integration. Before starting our journey of understanding of these concepts and technologies, let us have a look at the recent past; it will be beneficial in placing and judging things in the right perspective.

1.2 Design and Manufacturing: A Historical Perspective

1.2.1 Design

Design and manufacturing are the core activities for realizing a marketable and profitable product. A number of evolutionary changes have taken place over the past couple of decades in the areas of both design and manufacturing. First we explore the developments in what is called CAD. The major focus in CAD technology development has been on advancing representation completeness. Figure 1.2 shows the evolution of mechanical CAD/CAM systems over the past three decades. First there was the development of a two-dimensional (2D) drafting system in the 1960s. Then the extension of 2D drafting systems to three-dimensional (3D) models led to the development of wireframe-based modeling systems. However, it was not possible to represent higher order geometry data such as surface data. To bridge this gap, surface based models were developed in the early 1970s. Even though the surface models provided some higher level information, such as surface data for boundary representation, this was still not sufficient to represent solid or volume enclosure information. The need for solid modeling intensified with the development of application programs such as numerical control (NC) verification codes and automation mesh generation. A volume representation of the part is needed for performing topological validity checks. The solid modeling technology has evolved only since the mid-1970s. A large number of comprehensive software products are now available that enable integration of geometric modeling with design analysis and computer aided manufacturing. These software products include Pro/Engineer from Parametric Technology Corporation, IDEAS from SDRC, Unigraphics from Electronic Data Systems, and MES from Intergraph Corporation, among many others.

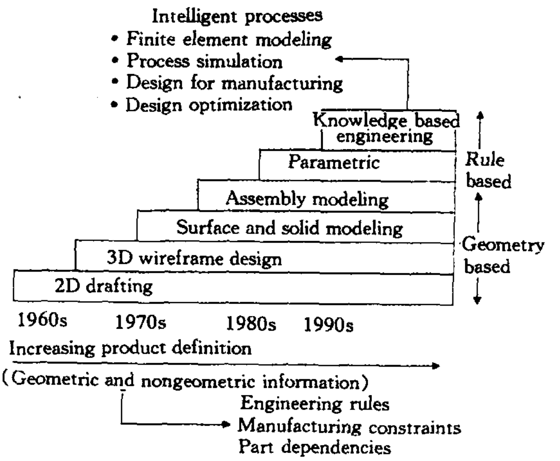

Figure 1.2 The envolution of mechanical CAD/CAM system

The solid modeling schemes provide mechanisms for defining informationally complete models. However, these schemes have an inherent weakness because they provide a low level representation of parts. That means that to model a part, the designer has to provide model description in terms of geometric and topological entities that constitute the model. For example, for a boundary representation of a part model, the designer has to specify curves and surfaces and their corresponding edges and faces or a Boolean combination of primitives for a constructive solid geometry (CSG)-based representation. For example, a solid model of a rotating shaft with one key stores information in terms of only edges and faces. Further developments in parametric modeling provide scope for a higher level of representation of model. Details of parametric and variational design are given in Chaper 3. These models provide only a higher level of abstraction of the underlying geometry and fail to capture the methodology used to design, configure, and assemble products.

The latest evolutionary development in the CAD/CAM industry has been knowledge-based engineering systems that can capture both geometric and nongeometric product information, such as engineering rules, part dependences, and manufacturing constraints, resulting in more informationally complete product definitions. The commercial knowledge based system known as Intelligent-CAD (ICAD) is available from ICAD, Cambridge, Massachusetts. Because ICAD is based on the principles of object oriented modeling technology, it provides a development environment with powerful geometric and artificial intelligence (AI)-based tools.

1.2.2 Manufacturing

Manufacturing is not just the transformation of raw materials into value-added outputs meeting specifications. It has a much broader meaning. The CAM-I definition of manufacturing essentially captures this broad meaning: Manufacturing is a series of interrelated activities and operations involving design, material selection, planning, production, quality assurance, management, and marketing of discrete consumer and durable goods.

This definition of manufacturing lays a foundation for the need for systems thinking. That means that, given the complexities involved in manufacturing because of the large number of interrelated activities, there is need for coordinated efforts from every organ of an organization. Furthermore, for a manufacturing organization to remain competitive, it must deliver products to customers at the minimum possible cost, the best possible quality, and the minimum lead time starting from the product conception stage to final delivery, service, and disposal. This implies the notion of the product life cycle approach to design and manufacturing. To accomplish these objectives, a high level of integration is required among all these activities.

Present-day manufacturing activities may be classified in two broad categories: continuous-process and discrete-product production. The focus of this book is on discrete-product manufacturing systems. To satisfy the order-winning criteria of low cost, high quality, and quick delivery response in a discrete-product manufacturing environment requires the combination of the attributes of mass production with those of a job shop. It is important to realize that systems based on the job shop concept have high product flexibility. That is, these systems are capable of making a variety of parts with ease but overall productivity tends to be low. On the other hand, mass production systems are dedicated to one type of product, which makes them much less flexible, but their level of productivity is much higher than that of comparable job shops. To address the problem of low productivity while retaining high levels of flexibility, new types of systems have been developed. These are called flexible manufacturing systems. FMSs rely heavily on computer controlled equipment such as computer numerical control (CNC) equipment, automated guided vehicles (AGVs), and robots. They are developed on the basis of group technology concepts making use of similarities in design attributes and manufacturing features. We will introduce some of these concepts later in this chapter, and they are discussed in detail in later chapters. Before that, let us quickly review the stages of developments in the field of manufacturing technology.

For all the advances in manufacturing we are indebted to our ancestors who developed the steam engine, water mills, wind mills, iron furnaces, and other innovations. The concept of division of labor, introduced by Adam Smith in 1776, had a profound influence on the creation of the factory system and on productivity improvement. Development of flow line assembly systems for engines by Henry Ford in 1913 was a giant step toward integrated manufacturing. This led to the realization of reduced labor and increased production rate. Frederick Taylor introduced the scientific approach to many such ideas. Other production specialists in the scientific management movement, such as Frank B, Gilbreth and Henry L, Gantt, made especially significant contributions. Gilbreth's primary contribution was the identification, analysis, and measurement of fundamental motions involved in performing work. Gantt devised the so-called Gantt chart which provides a systematic graphical procedure for preplanning and scheduling work activities, reviewing progress, and schedule updating. The Great Depression of 1929 forced everyone to think in a new direction requiring employee motivation and satisfaction, which led to the development of the idea of job enrichment and enlargement.

In the area of machines, Devol G C developed a controller device in 1946 that could record electrical signals magnetically and play them back to operate a mechanical machine (U.S. patent issued in 1952). A number of interesting developments since then in the areas of numerically controlled machine tools, robotics, material handling systems, and computer control systems have led to the current state of automated manufacturing technology, such as flexible manufacturing systems. We provide a brief historical perspective on each of these.

(1) *Numerically Controlled Machines*

The first successful numerically controlled machine was demonstrated at the Massachusetts Institute of Technology (MIT) under a subcontract from Parsons Corporation of Traverse City, Michigan, funded by the U. S. Air Force in the 1950s. Automatic tool changers and indexing worktables were added in the 1960s. During this period the concept of direct numerically controlled (DNC) systems, in which several NC machines are linked to a main computer, was developed. Control system development in 1971 was the next milestone and led to the introduction of microcomputer controlled NC machines, also called CNC machines. The major advantage of CNC was the ability to store many part programs in memory, in addition to communicating with other controllers or a central computer. The advantages of CNC and DNC were combined in other systems that are also known as DNC, but here DNC stands for distributed numerically controlled. In such DNC systems several CNC machines are linked to a main host computer. In the 1980s CNC machines were further developed by making them capable of carrying hundreds of tools, having multiple spindles, and controlling movements in up to six axes. These capabilities, coupled with developments in computer communications technology, have led to advances in automated manufacturing systems such as computer integrated manufacturing systems. In a separate chapter we discuss not only NC, CNC, and NC part programming but also programmable logic controllers and computer control.

(2) *Material Handling Systems*

Material handling is an integral part of any manufacturing system. Manufacturing system performance can be significantly improved by using computer controlled material flow, which reduces waiting time and work-in-process inventory compared with manual loading and unloading and manual material handling systems. To this end, developments in floor-mounted and overhead roller conveyors, stacker cranes, and automated guided vehicles have contributed substantially to smooth material flow on the factory floor. Through a system of programmable logic controllers, computers, and computer networks, the material handling systems, material storage systems, and machine tools can be integrated to configure an automated manufacturing system to meet customer requirements.

(3) *Robotics*

The word "ROBOT" was first used to mean "forced labor" in a satirical fantasy play, "Rossum's Universal Robots," written by Karel Capek in 1921. Robotics, along with the technological developments in the areas of microprocessor and numerical control, have advanced the frontiers of automation. The technology for the present generation of robots was developed by Cyril Walter Kenward in 1954 in Britain and G.C. Devol in the United States. The first computer-type robot programming language was developed at Stanford Research Institute (SRI) in 1973 for research called WAVE, followed by the language AL in 1974. The two languages were subsequently developed into the commercial VAL language for Unimation by Victor Scheinman and Bruce Simano. In the 1980s several off-line programming systems were developed. Since then, several types of robots have been built and several robot programming languages have been developed. Robots are being used in industry for applications including painting, welding, material handling, and assembly.

(4) *Computer Control Systems*

Computer control systems have provided a major impetus to automaton. The use of mainframe computers in the 1950s and 1960s for planning, scheduling, and controlling batch production became quite commonplace. A number of management information systems and database management systems were developed and used for a variety of functions in companies. Accounting, payroll, shop floor control, and maintenance information systems are a few examples. Factory automation also resulted from advances in local area and wide area networks (LANs and WANs), bar codes, programmable logic controllers

(PLCs), and computer controls. Automatic identification technology such as bar code systems, automatic data collection and analysis systems, and real-time transfer of information provided a stimulus to the growth of factory automation.

(5) *Flexible Manufacturing Systems*

The technological developments in CNC, DNC, PLC, robotics, AGVs, automated storage and retrieval systems (AS/RSs), automatic tool changers, tool magazines, modular fixturing, local area networks, and associated technologies such as group technology laid foundations for automated manufacturing of a high to medium variety of parts having low to medium levels of demand. This led to the evolution of FMSs in the early 1960s. The Sunstrand Corporation was one of the first to develop such systems to manufacture a variety of aircraft gearbox casings. The system had eight NC machine centers and two multi-spindle drills linked by a computer controlled roller conveyor system. Although it did not have the flexibility of current-day FMSs, it was the first system with built-in automated material flow integration. Current systems provide higher levels of flexibility and a high degree of automation.

(6) *Other Significant Supporting Technologies*

Besides developments in the areas already mentioned, the need for reduced cost and lead time and high quality led to the introduction of quality engineering approaches to product design. Notable among these is the Taguchi method of product design, which introduced the concept of loss function and signal-to-noise ratio for product design. Material requirements planning and manufacturing resource planning, just-in-time manufacturing philosophy, group technology, and cellular manufacturing led to significant changes in the way production is now planned and controlled at the shop floor.

1.3 Systems Approach to Computer Integrated Design and Manufacturing

A system can be defined as a collection of components in which individual components are constrained by connecting interrelationships such that the system as a whole fulfills some specific functions in response to varying demands. This suggests a well-known input-output framework for defining systems. In the case of manufacturing systems, the inputs include related strategies, technology, business processes, and people. The outputs are the products or services that help realize the goals of a manufacturing enterprise. A product has to be understood in a much broader context. What mattes is the overall performance of the product during its life cycle. Therefore, the product life cycle approach provides a logical framework for understanding and analysis.

Opportunities for reduction in cost and lead time and improvements in product quality must be sought from all the areas of a product life cycle. The product life cycle includes the following phases:

• Design phase;

• Manufacturing phase;

• Product usage phase;

• Disposal phase.

During the product life cycle, design and manufacturing have major effects on the subsequent phases. Consequently, they are responsible for the lion's share of life cycle cost as shown in figure 1.3. The issues of product quality and overall lead time are intimately tied to these phases. Looking exclusively at a single phase of the life cycle will miss the dependences that exist between them. Obviously, what is needed is a systems approach to understand each of the phases and the linkages between them.

Product design sets the stage for product success or failure in the marketplace. The reason is that product design has a direct impact on product cost, quality, and reliability; introduction intervals, manufacturing process yields; future maintenance costs; and cost to dispose of the product. Typically, 80% of the cost of a product is fixed at the design stage, as shown in figure 1.3. We need a concurrent engineering approach to consider the interaction between various phases of the product life cycle.

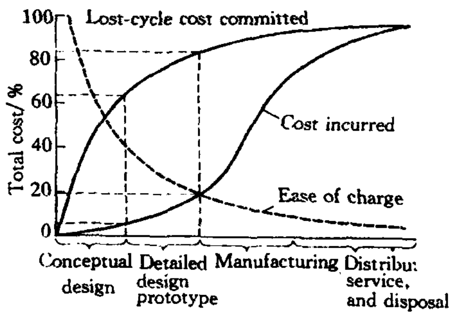

Figure 1.3 Characteristic curve representing cost incurred and committed during product life cycle

The product design process starts with the identification of customer needs and goes through a sequence of activities. These include:

• Identifying the attributes of the need for which the product is being designed and defining the problem domain.

• Generation of preliminary ideas with respect to technical choices, materials, design complexities, and so on.

• Refinement of the product ideas using geometric modeling.

• Analysis of best designs from the point of view of cost, functional requirements, and marketability using such tools as finite-element methods, assembly analysis, and so on.

• Selection of a design that has all the desirable characteristics including manufacturability, serviceability, maintainability, et cetera.

• Creation of a detailed design providing detailed specifications with respect to materials, tolerances, surface roughness, and so on.

1.4 Organization

(1) *Computer Aided Design: Design Process, CAD Hardware, Computer Graphics, and Transformations*