

# CHAPTER 1

## Introduction to CAD/CAM/CAE Systems

### 1.1 OVERVIEW

Today's industries cannot survive worldwide competition unless they introduce new products with better quality (quality, Q), at lower cost (cost, C), and with shorter lead time (delivery, D). Accordingly, they have tried to use the computer's huge memory capacity, fast processing speed, and user-friendly interactive graphics capabilities to automate and tie together otherwise cumbersome and separate engineering or production tasks, thus reducing the time and cost of product development and production. Computer-aided design (CAD), computer-aided manufacturing (CAM), and computer-aided engineering (CAE) are the technologies used for this purpose during the product cycle. Thus, to understand the role of CAD, CAM, and CAE, we need to examine the various activities and functions that must be accomplished in the design and manufacture of a product. These activities and functions are referred to as the product cycle. The product cycle described by Zeid [1991] is presented here with minor modifications, as shown in Figure 1.1.

As indicated by the boxes bounded by solid lines in Figure 1.1, the product cycle is composed of two main processes: the design process and the manufacturing process. The design process starts from customers' demands that are identified by marketing personnel and ends with a complete description of the product, usually in the form of a drawing. The manufacturing process starts from the design specifications and ends with shipping of the actual products.

The activities involved in the design process can be classified largely as two types: synthesis and analysis. As illustrated in Figure 1.1, the initial design activities (such as identification of the design need, formulation of design specifications,

feasibility study with collecting relevant design information, and design conceptualization) are part of the synthesis subprocess. That is, the result of the synthesis subprocess is a conceptual design of the prospective product in the form of a sketch or a layout drawing that shows the relationships among the various product components. The major financial commitments needed to realize the product idea are made and the functionality of the product is determined during this phase of the cycle. Most of the information generated and handled in the synthesis subprocess is qualitative and consequently is hard to capture in a computer system.

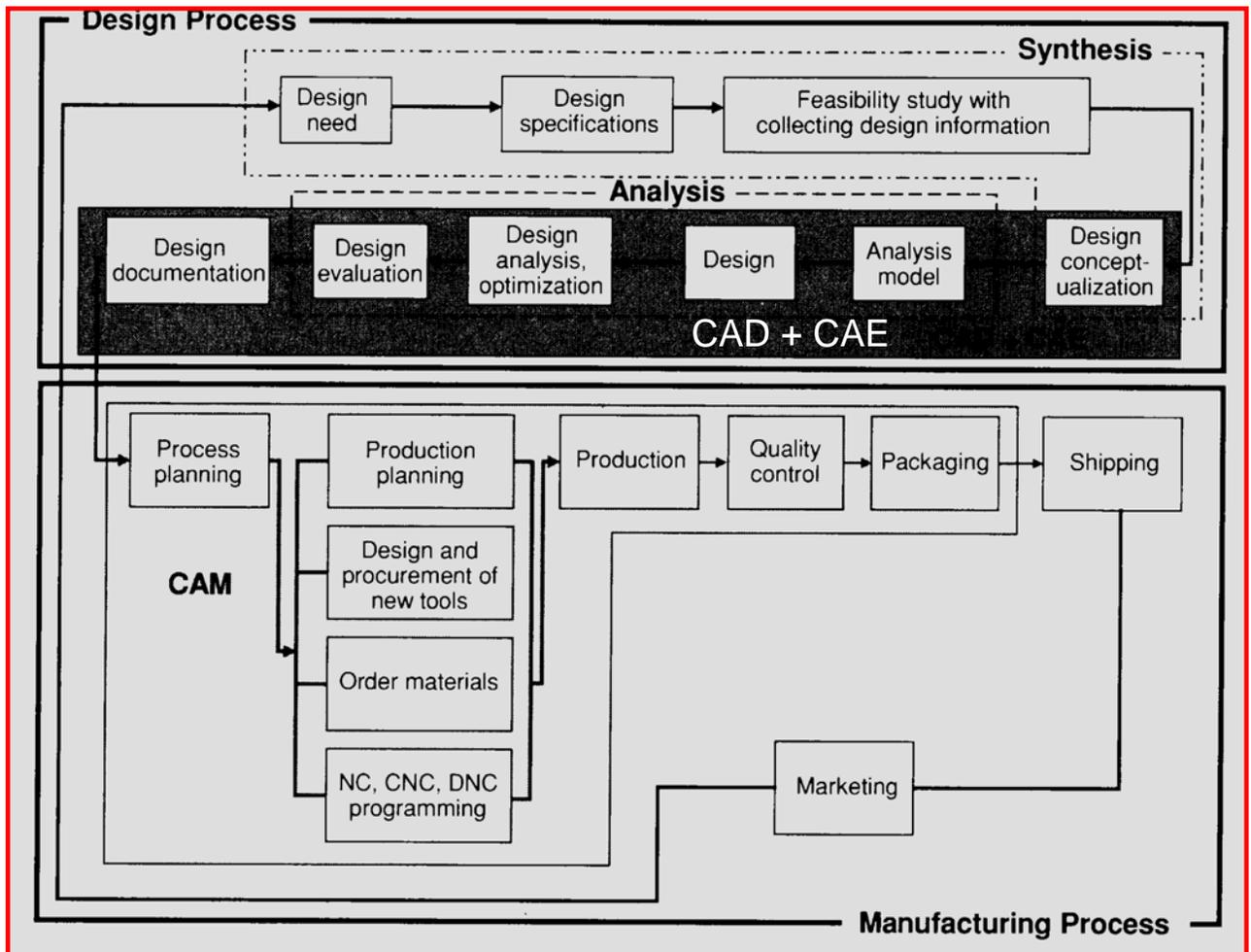


Figure 1.1 Product Design Cycle

Once the conceptual design has been developed, the analysis subprocess begins with analysis and optimization of the design. An analysis model is derived first because the analysis subprocess is applied to the model rather than the design itself. Despite the rapid growth in the power and availability of computers in engineering, the abstraction of analysis models will still be with us for the foreseeable future. The analysis model is obtained by removing from the design unnecessary details, reducing dimensions, and recognizing and employing symmetry. Dimensional reduction, for example, implies that a thin sheet of material is represented by an equivalent surface with a thickness attribute or that a long slender region is represented by a line having cross-sectional properties. Bodies with symmetries in their geometry and loading are usually analyzed by considering a portion of the model. In fact, you have already practiced this abstraction process naturally when you analyzed a structure in an elementary

mechanics class. Recall that you always start with sketching the structure in a simple shape before performing the actual analysis. Typical of the analysis are stress analysis to verify the strength of the design, interference checking to detect collision between components while they are moving in an assembly, and kinematic analysis to check whether the machine to be used will provide the required motions. The quality of the results obtained from these activities is directly related to and limited by the quality of the analysis model chosen.

Once a design has been completed, after optimization or some tradeoff decisions, the design evaluation phase begins. Prototypes may be built for this purpose. The new technology called rapid prototyping is becoming popular for constructing prototypes. This technology enables the construction of a prototype by depositing layers from the bottom to the top. Thus it enables the construction of the prototype directly from its design because it requires basically the cross-sectional data of the product. If the design evaluation on the prototype indicates that the design is unsatisfactory, the process described is repeated with a new design.

When the outcome of the design evaluation is satisfactory, the design documentation is prepared. This includes the preparation of drawings, reports, and bills of materials. Conventionally, blueprints are made from the drawings and passed on to manufacturing.

As illustrated in Figure 1.1, the manufacturing process begins with process planning, using the drawings from the design process, and it ends with the actual products. Process planning is a function that establishes which processes—and the proper parameters for the processes—are to be used. It also selects the machines that will perform the processes, such as a process to convert a piece part from a rough billet to a final form specified in the drawing. The outcome of process planning is a production plan, a materials order, and machine programming. Other special requirements, such as design of jigs and fixtures, are also handled at this stage. The relationship of process planning to the manufacturing process is analogous to that of synthesis to the design process: It involves considerable human experience and qualitative decisions. This description implies that it would be difficult to computerize process planning. Once process planning has been completed, the actual product is produced and inspected against quality requirements. Parts that pass the quality control inspection are assembled, functionally tested, packaged, labeled, and shipped to customers.

We have described a typical product cycle. Now we will review it to show how the computers, or CAD, CAM, and CAE technologies, are employed in the cycle. As indicated earlier, the computer is not widely used in the synthesis.

Phase of the design process because the computer does not handle qualitative information well. However, in the synthesis subprocess, for example, a designer might well collect the relevant design information for the feasibility study by using a commercial database and collect catalog information in the same way.

Nor is it easy to imagine how a computer might be used in the design conceptualization phase because the computer is not yet a powerful tool for the intellectual creative process. The computer may contribute in this phase by physically generating various conceptual designs efficiently. The parametric modeling or macro programming capability of computer-aided drafting or geometric modeling may be useful for this task. These packages are typical examples of CAD software. You may imagine a geometric modeling system to be a three-dimensional equivalent of a drafting system; that is, it is a software package by which a three-dimensional shape instead of a two-dimensional picture is manipulated. We explain computer-aided drafting in Chapter 4 and geometric modeling in Chapter 5.

The analysis subprocess of the design process is the area where the computer reveals its value, in fact, there are many available software packages for stress analysis, interference checking, and kinematic analysis, to name a few. These software packages are classified as CAE. One problem with using them is the provision of the analysis model. It would not be a problem at all if the analysis model were derived automatically from the conceptual design. However, as explained previously, the analysis model is not the same as the conceptual design but is derived by eliminating unnecessary details from the design or by reducing its dimensions. The proper level of abstraction differs, depending on the type of analysis and the desired accuracy of the solution. Thus it is difficult to automate this abstraction process; accordingly the analysis model is often created separately. It is a common practice to create the abstract shape of the design redundantly by using a computer-aided drafting system or a geometric modeling system or sometimes by using the built-in capability of the analysis packages. Analysis packages usually require the structure of interest to be represented by an aggregation of interconnected meshes that divide the problem into manageable chunks for the computer. If the analysis package being used has the capability of generating these meshes automatically, it would be necessary to create the abstract boundary shape only. Otherwise, the meshes also have to be generated either interactively by the user or automatically by appropriate software. This activity of generating meshes is called finite-element modeling. Finite-element modeling also includes the activity of specifying boundary conditions and external loads.

The analysis subprocess can be imbedded in the optimization iteration to yield the optimal design. Various algorithms for finding the optimal solution have been developed, and many optimization procedures are commercially available. Optimization procedures could be thought of as a component of CAD software, but it is more natural to treat optimization procedures separately.

The design evaluation phase also can be also facilitated by use of the computer. If we need a design prototype for the design evaluation, we can construct a prototype of the given design by using software packages that automatically generate the program that drives the rapid prototyping machine. These packages are classified as CAM software, which we define later. Of course, the shape of the prototype to be made should exist in advance in a type of data. The data corresponding to the shape are created by geometric modeling. We present an overview of the existing rapid prototyping technologies in Chapter 12. Even though the prototype can be constructed conveniently with rapid prototyping, it would be even better if we could use a virtual prototype, often called digital mock-up, which provides the same valuable information.

As the analysis tools used to evaluate the digital mock-up become powerful enough to give an analysis result as accurate as that from the equivalent experiment on a real prototype, digital mock-ups will tend to replace real prototypes. This tendency will increase as virtual reality technology' enables us to get the same feeling from the digital mock-up as we get from the real prototype. The activity of building digital mock-ups is called virtual prototyping. The virtual prototype can also be generated by a kind of geometric modeling that is specialized for that purpose. We describe virtual prototyping in detail in Chapter 13.

The final phase of the design process is design documentation. In this phase, computer-aided drafting is a powerful tool. The file-handling capability of computer drafting systems also allows the systematic storage and retrieval of documents.

Computer technologies are also used in the manufacturing process. The manufacturing process includes the activities of production planning, design and procurement of new tools, ordering materials, NC programming, quality control, and packaging, as illustrated in Figure 1.1, so all the computer technologies for these activities can be classified as CAM. For example, computer-aided process planning (CAPP) software to aid the process planning activity is one type of CAM software. As mentioned previously, process planning is difficult to automate, and thus 100 percent automatic CAPP software is not available currently. However, there are many good software packages that generate the numerically controlled (NC) programs that drive NC machines. This

type of machine creates a given shape when the shape exists the computer in the form of data. This is similar to driving the rapid prototyping machine. The NC programming capability is explained in Chapter 11. In addition, also belonging to CAM are the software packages to program robot motion to assemble components or deliver them to the various manufacturing activities, or to program a coordinate measuring machine (CMM) to inspect the product.

By now you should have an idea of how computer technologies are employed in the product cycle and which tasks are facilitated by CAD, CAM, and CAB. We define these technologies in the following section.

## 1.2 DEFINITIONS OF CAD, CAM, AND CAE

As described in the previous section, computer-aided design (CAD) is the technology concerned with the use of computer systems to assist in the creation, modification, analysis, and optimization of a design [Groover and Zimmers 1984]. Thus any computer program that embodies computer graphics and an application program facilitating engineering functions in the design process is classified as CAD software. In other words, CAD tools can vary from geometric tools for manipulating shapes at one extreme, to customized application programs, such as those for analysis and optimization, at the other extreme [Zeid 1991]. Between these two extremes, typical tools currently available include tolerance analysis, mass property calculations, and finite-element modeling and visualization of the analysis results, to name a few. The most basic role of CAD is to define the geometry of design—a mechanical part, architectural structure, electronic circuit, building layout, and so on—because the geometry of the design is essential to all the subsequent activities in the product cycle. Computer-aided drafting and geometric modeling are typically used for this purpose. This is why these systems are considered CAD software. Furthermore, the geometry created by these systems can be used as a basis for performing other functions in CAB and CAM. This is one of the greatest benefits of CAD because it can save considerable time and reduce errors caused by otherwise having to redefine the geometry of the design from scratch every time it is needed. Therefore we can say that computer-aided drafting systems and geometric modeling systems are the most important components of CAD.

Computer-aided manufacturing (CAM) is the technology concerned with the use of computer systems to plan, manage, and control manufacturing operations through either direct or indirect computer interface with the plant's production resources. One of the most mature areas of CAM is numerical control, or NC. This is the technique of using programmed instructions to control a machine tool that grinds, cuts, mills, punches, bends, or turns raw stock into a finished part. The computer can now generate a considerable amount of NC

instructions based on geometric data from the CAD database plus additional information supplied by the operator. Research efforts are concentrating on minimizing operator interactions.

Another significant CAM function is the programming of robots, which may operate in a workcell arrangement, selecting and positioning tools and workpieces for NC machines. These robots may perform individual tasks such as welding or assembly or carry equipment or parts around the shop floor.

Process planning is also a target of computer automation; the process plan may determine the detailed sequence of production steps required to fabricate an assembly from start to finish as it moves from workstation to workstation on the shop floor. Even though completely automatic process planning is almost impossible, as mentioned previously, a process plan for a part can be generated if the process plans for similar parts already exist. For this purpose, group technology has been developed to organize similar parts into a family. Parts are classified as similar if they have common manufacturing features such as slots, pockets, chamfers, holes, and so on. Therefore, to automatically detect similarity among parts, the CAD database must contain information about such features. This task is accomplished by using feature-based modeling or feature recognition. Feature-based modeling and feature recognition are explained in Chapter 5. Group technology is explained in Chapter 10.

In addition, the computer can be used to determine when to order raw materials and purchase parts and how many should be ordered to achieve the production schedule. This activity is called material requirements planning (MRP). The computer can be also used to monitor the status of the machines on the shop floor and to send them the proper orders.