Chapter 1

Engineering a Product

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INTRODUCTION

This chapter presents an overview of manufacturing life cycle engineering for a typical durable good. A durable good is a product that is intended for repeated use and extended service. Examples of durable goods are automobiles, aircraft, machine tools and coffee makers. In this chapter we describe the impact of technology and modern methods of organizing operations on the factories of today and tomorrow. To function successfully in these factories, the current generation of product, manufacturing, and industrial engineers must understand and make use of the connectivity that results from electronic communications systems. This connectivity links manufacturers, customers, and suppliers, enabling manufacturers to streamline their operations and provide customers with goods and services at competitive prices. For example, new integrated circuit designs are distributed electronically so that prototyped components can be reviewed and manufactured quickly and inexpensively. Very complex designs are shipped electronically, and manufactured remotely so that affordable electronic and mechanical products can be provided in a timely manner. Future manufacturing capabilities will span a range of activities that depend on electronic communication systems. This connectivity will link manufacturers (designers, planners, and production personnel), customers, and suppliers so that information processing will become increasingly responsive and effective.

Engineers of the 21st century will require an increasingly broad set of technical and business skills. Today’s technical environment already includes design, planning for manufacture, manufacture, qualification (i.e.; inspection and approval), marketing, and maintenance of a product. In the future, engineers will also address business requirements to include: marketing, capital equipment justification and procurement, pricing and capitalization. In general, engineers will provide the required information for both the business and technical integration required to link engineering and business. Integration of design with manufacturing requires that engineers, production personnel, and managers share the information needed to produce a durable good.

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In addition to understanding the impact of technology on operations, the successful engineer must master a range of technical and business skills. Companies face an increased global competition for their manufactured goods and must operate efficiently, reduce costs, and satisfy their customers. Even at the design stage, engineers must look ahead to the market demand for the product and the qualities that customers require. Today’s and tomorrow’s engineers must realize the impact of design and planning on manufacture, the impact of manufacturing on marketing, and the tasks required to maintain the product while it is being used. In this chapter, we explain how product planning shapes manufacturing processes in this environment.

The integration of design, planning for manufacture, and the manufacture of the product is the central theme of this book. In this chapter and throughout the text, we highlight the decision-making processes necessary for manufacturing a durable good, particularly the design decisions that foster efficient manufacturing processes and the manufacturing decisions that affect the quality of a design. Good engineering is no longer just a local activity. In order for an engineer to be effective, they must consider the impact of their design decisions on upstream and downstream activities.

1.1 Engineering Past and Present

As the industrial revolution began in the United States in the early 1900’s, the principal focus of engineering has matured to systematize manufacturing and to reduce the workforce required to produce a product or perform a task. The past three decades of engineering have brought the computer to business managers, engineers, and the shop floor. The computer has served to provide fast, immediate computation and improved information processing. Business activities including accounting, billing, payroll, order entry and bill of material processing were among the first activities to be automated. The computer was first used in engineering to assist in difficult analysis activities and has evolved into today's engineering workstation. Currently, engineers initiate drawings on a Computer-Aided Design (CAD) system, analyze the engineering characteristics of their design, optimize design parameters, plan a process to create the parts they are going to make, and generate machine instructions using a workstation or network of workstations. Production engineering activities include inventory management and control, resource planning, scheduling and shop floor control, all of which can be performed using a computer network. Business managers, engineers, and manufacturing personnel use computer communication networks to share large amounts of information.

Traditionally, engineering activities have been separated into departments, with tasks needed to produce a product performed sequentially. Engineers have viewed their job as a set of serial activities. A **product engineer** is someone who defines and details product requirements and then passes these specifications (typically as an engineering drawing) to a **process engineer**. The **process engineer** then determines what manufacturing resources are required to produce the product and details a set of manufacturing instructions or process plans. Finally, the **production engineer** schedules and supervises the manufacture of the product. In the past, the only link between each engineering activity has been the product. Communication between the
engineering units has been minimal; hence, design for manufacturability has received far less emphasis than design for function.

As seen in Figure 1.1, the product engineer produces an **engineering design**. This engineering design is then passed to Process Engineering, which creates **process plans**, instructions as to how the product will be manufactured. The engineering design and process plans are then forwarded to manufacturing where the product is produced. **Manufacturing** is the process of converting an item from one form to another; thereby, adding value to the initial form. This process and the activities illustrated in Figure 1.1 are sometimes described as **waterfall engineering** because the flow of information is downstream with little opportunity for feedback.

![Diagram of traditional manufacturing life cycle](image)

**Figure 1.1** Traditional manufacturing life cycle.

Today’s communication and information technologies have made it almost impossible for a modern engineer to be isolated from other engineering and business activities. Many of the United States’ foreign competitors have recognized significant product, process, and production improvements from broadening the boundaries of engineering and business activities. Although there is no typical specification or method for integrating engineering and business activities, striking results have been realized when these activities have been performed simultaneously. Creating teams consisting of members of various engineering and business organizations has produced good results even if the dynamics and interactions of the teams are not particularly well understood.
1.2 Manufacturing Life Cycle

Engineering is the planning, designing, construction (manufacture), or management of machinery, roads, bridges, etc. [Webster, 2000]. This definition of engineering uses the conjunction or to connect the linkage of engineering activities, which implies that these activities are performed somewhat independently. As engineering has evolved over the past hundred years, most engineering departments have segregated the functional activities that engineers perform. For instance, product engineering, tool engineering, and quality engineering are some common department names found in industry. Today, it is becoming increasingly critical that modern engineers are involved with a broader set of activities and have an understanding of how their decisions affect other functions.

A product life cycle is the period from the conception of a product, through its manufacturer, to the normal operation and maintenance, terminating with the disposal of the product. Many countries are charging the manufacturer of a product with the disposal of the product at the end of the product's useful life. In Europe, automobiles manufactured after the year 2000 become the responsibility of the manufacturer to separate into base materials or reusable components after the useful life of the automobile has been reached. It is easy to see that it is critical for an engineer to understand the functional implication of selecting the most appropriate materials for a product from a functional point of view. However, it is becoming equally important for today's engineer to understand what will happen to those materials when the life of a product is complete. Disposal, recycling, reuse, maintenance, and remanufacturing a product are critical elements of design today [Hyman, 1998; Dhillon, 1996]. A good example of this situation is the growing stockpile of worn tires, outdated computers, and lead-acid batteries.

The manufacturing life cycle is the period from the conception of a product up to shipping the product to a customer. If a product cannot be designed so that it is easily (and inexpensively) manufactured, then it is doomed to fail regardless of the functionality of the product. Product planning, design, manufacture and management are components of the manufacturing life cycle. Traditionally, the manufacturing life cycle begins with product design. Once a product design is finalized, a process engineer develops plans to produce the product. Finally, production engineering is responsible for the manufacture and qualification of the product. The basis of concurrent engineering is that all engineering activities are expected to occur in parallel, i.e., design, process engineering and production engineering. A more appropriate term would be integrated engineering where the planning, designing, manufacturing and management of a product are all viewed as one activity.

Traditionally, the engineering activities associated with the manufacturing life cycle have been conducted sequentially as shown in Figure 1.1. This had created an environment where the designer has taken little responsibility of how the product was going to be produced. Farther downstream, the process engineer felt little empathy for how much work was at a specific manufacturing center, so he planned a new product without considering some critical production requirements, and so on. Some industries required feedback between the engineering functions, but this was more to correct problems that had occurred rather than to prevent them from occurring. In the 1970's, U.S. production costs were high, our product quality was no longer the very best, and the time required to bring an engineering idea to market was greater than what
consumers expected. One of the reasons for this situation was the way in which the Manufacturing Life Cycle was conducted.

Figure 1.2 represents an integrated view of the manufacturing engineering life cycle where Product Engineering (Design), Process Engineering, and Production Engineering are spokes of the manufacturing engineering life cycle wheel. At the hub of the wheel is the product model. The product model is the collection of the engineering drawing, process plans, and miscellaneous production information necessary to manufacture the product. This product model is truly the entity around which everything else revolves. If the spokes of the wheel are laid out in the order of product, process and production engineering, then engineering occurs as it has traditionally (Figure 1.1). As a wheel revolves to each of the activities, integration occurs between the spokes of the wheel that is between the engineering functions. This wheel represents engineering activities being performed in tandem and is a vision of concurrent engineering.

![Figure 1.2 Manufacturing life cycle engineering wheel.](image-url)
1.2.1 Product Engineering

Product engineering begins with the development of an aggregate product model, which contains *form* and *function* but little *tolerance information or detail*. When the product engineer is satisfied with the initial aggregate design concepts, he/she creates a more detailed dimensional model. When the designer feels that he/she has developed the concept to the point where "form and fit" can be detailed, tolerance specifics are added to the model. The output from product engineering is an **engineering design**. This engineering design has traditionally been communicated on a blueprint. Today, the engineering design may take several forms, which may include a rendering on a Computer Aided Design (CAD) system. The specific requirements of an engineering design are discussed in more detail in Chapter 2.

1.2.2 Process Engineering

Process engineering usually begins with an engineering drawing or the initial product model. From a drawing, process engineers develop manufacturing plans to produce the product. Process engineers use the product model and the expected quantity to be produced coupled with knowledge of how similar parts and part features have been produced in the past in order to create a set of manufacturing plans. Process engineers should also bring features that are hard to manufacture to the attention of designers so that alternative designs can be developed which are less costly and easier to produce. When process engineers complete their initial pass at producing the manufacturing plans, they expand the product model to include both design and processing information. The product model then consists of both the engineering design and the process plans.

1.2.3 Production Engineering

Production engineering includes all of the manufacturing activities required to produce a product as well as those activities required to control and manage the flow of the product through the manufacturing facility. Facilities design and analysis are also conducted as a part of production engineering. Machine requirements planning, which includes design and procurement of special tools, capacity resource planning, systems management and control, and the basic manufacturing processing, occurs in the production engineering function. The existing facility as well as the knowledge of the facility can drive much of the design and virtually all of the process engineering function. Production engineers may also identify inconsistencies in the plans provided from process engineering as well as design anomalies on the engineering drawing.

1.2.4 Engineering Integration

Integrating each of these engineering activities within the manufacturing engineering life cycle wheel is critical to the success of any firm. Because of the specialization that has occurred, (for example, designers can be specialized within a particular focus such as drive train activities), coordinating engineering activities within an engineering discipline as well as between disciplines is key to successful engineering. Each of the engineering functions is punctuated with integration issues. For instance within Production Engineering, the capacity of a facility is a function of the machinery that is used to produce products. However, the organization of the
machinery as well as the control system used to sequence products through the system can significantly affect the utilization of the equipment. Planning, design and control issues must all be coordinated very carefully.

The product model remains the hub of engineering activities and especially those activities conducted by manufacturing (process and production) engineers. A designer (product engineer) develops and refines the initial representation of the product model - the engineering design. The process engineer then examines this design so that a process model of the design can be developed -- the new product model. This product model is then given to the production engineer so that a further refinement in the product specification can be made. The production engineer determines whether the product can be produced in desired quantities on a given time schedule using existing equipment and facilities or whether new resources are required. Many iterations (or revisions) of these engineering activities are required in order to develop a good or optimum product model, where function is maintained and cost effectiveness and quality maximized.

### 1.2.5 Product Life Cycle Engineering

Figure 1.3 is an even broader perspective of engineering—product life cycle engineering. Product life cycle engineering extends from product concept, to product disposal, not just product production. This expands the manufacturing life cycle to include out-going product quality, reliability, maintainability, and disposability. Engineers throughout the world are adopting this extended view of the product life cycle. In Europe, manufacturers are responsible for reducing a “spent” automobile to used part components (a rebuilt engine) or basic material elements (iron, copper, and so forth) puts further pressure on the designer. Designing a product for easy assembly was difficult; designing a product for disassembly and maintenance is even more of a challenge. An offshoot of this is that many designers had hypothesized that composite materials would be used to a large extent for structural components in automobiles. Because of the difficulty of separating composites, this alternative has virtually been dismissed for high-volume production vehicles. Engineers must include decisions about manufacturing, recycling, and environmental effects of products during each phase of engineering.

It is important that products be designed and manufactured right the first time. An estimated 70 - 85% of the product's cost is committed by the decisions made during product engineering even though design typically represents only 10 - 25% of the engineering costs. The impact of product engineering on cost highlights the importance of making available cost information at the early stages of design, e.g., how expensive are design features to manufacture and maintain? Traditionally, product cost is determined after a design is completed and is normally performed by trained cost estimators. Coordination between product, process, and production engineers is another way to both predict and reduce cost. Recently, design teams have been established to explore alternative designs, including an economic evaluation, which is conducted for each design alternative. This has been reasonably effective in the design of relatively high volume products, but can be costly for low volume products. It also extends the time-to-market cycle for all products.
The astute engineer utilizes cost functions to synthesize the design from the initial CAD representation to production. It is no longer appropriate to separate the technical and economic features of design. Cost estimators will no longer do post-design estimating, processing, and manufacturing planning, but these activities will be conducted in conjunction with the product design. Designs will be studied off-line, but by the designer, who will immediately assess the cost, manufacturability, in-process and final yield, and economic performance.

1.3 Concurrent Engineering

In the 1980s, many Japanese and European firms began performing the various engineering activities concurrently. The results of these "concurrent" activities were higher quality and less expensive products being produced in shorter times thus challenging the leadership that many U.S. manufacturers held in markets for durable goods. Faced with declining market share, many U.S. manufacturers adopted a new engineering philosophy called Concurrent Engineering.
**Concurrent engineering** is defined as a systematic approach to integrated product, process and production engineering (and their related processes, including cost estimation, tool engineering, purchasing, and related business functions). The goal of concurrent engineering is to perform all manufacturing life cycle activities simultaneously so that the product will meet the customer's requirements to the fullest extent and be realized in minimum time.

In the traditional manufacturing life cycle, manufacturers used a sequential series of steps to produce a product to market. During the conceptual design and preliminary development stages, product engineers have played a dominant, almost exclusive role. Prototypes (first item products) developed from the initial design were given to the process engineers so that the product could be produced in the required production volume and to the required specifications. In order to ensure that parts and materials were available for assembly, procurement experts stepped in at the next stage of product development. Finally, marketing and sales personnel introduced the product to the consumer. This serial approach led to several drawbacks in the form of longer development cycles, increased manufacture cost (again, up to 80% of the production cost may be specified before manufacturing engineers have a voice in process design), and a product that is not optimal for the market that exists.

We represent concurrent engineering in Figure 1.2 as a three spoke wheel where the activities on all three spokes are performed at the same time, and the product, process, and production engineers communicate with one another. Product design defines the features and their attributes, which coupled with the process knowledge base dictates how manufacturable a product, will be. The process engineering and production engineering interface defines the capabilities of a manufacturing system. The product and production engineering interface dictates a product's performance in the marketplace, i.e., how well it meets its functions, how reliable it is in use, how comfortable the user feels with the product, and many other product life cycle issues.

Product design begins when the product engineer specifies the attributes of a new product. The **current product model** is produced from the first pass at product engineering. The current product model is embellished by the process engineer to include process-related attributes, process plans such as: knurl surface, heat treat, and so on. The production engineering completes the product model by adding all of the tooling required and completing first item fabrication as well as production fabrication requirements. The first item to be produced, often referred to as a prototype, is frequently produced very differently than production based units. The first item is, however, critical in understanding some physical functions as well as some manufacturing attributes such as feature accessibility. Concurrent design (designing the product, the processes and the production facility at the same time) is an important aspect of concurrent engineering.

The goals of concurrent design are two-fold: to enhance the effectiveness of a product by incorporating all relevant knowledge at the design stage, and to increase the efficiency of the design process by reducing turnaround time from product conception to delivery. By so doing, a company is able to meet both the market opportunities and market demands.
When applied effectively and with a company-wide commitment, the following benefits of concurrent engineering are achievable:

- A high-quality, lowest-cost product that meets the customers' needs.
- A decrease in the overall product-development time.
- Improved time to market by reducing the number of product interactions since first prototypes meet specifications and are competitive with the company's manufacturing capabilities.
- Higher sales and profits because a greater variety of products can be supported and targeted toward more segments of the market.
- Lower capital equipment costs.
- Greater use of automation.
- Less chance of re-design.
- Fewer parts to purchase from fewer vendors.
- Better factory utilization.

Concurrent engineering has opened many doors for manufacturers who seek a rational, comprehensive plan to improve the overall operations of the firm, from design to manufacturing to delivery.

1.4 Implementing Concurrent Engineering

Concurrent Engineering (CE) is a very broad concept based on the integration of different disciplines in the development of a product and the control of its evolution during its life cycle [Hyman, 1998]. Strategies that serve as tools to CE are for example: Design for “X” tools (where “X” stands for different life cycle concerns such as manufacturing, assembly, reliability, serviceability, robustness, etc.) Total Quality Control (TQC), Just in Time (JIT), Computer Integrated Manufacturing (CIM) and Human Resource management. These strategies comprise methods that are directed toward the improvement of product quality with lower cost, better reliability and good availability as a means to obtain a competitive advantage in the global market. None of these CE tools represents the best solution to the transformation that manufacturing firms must endure to ensure their survival in the marketplace; this solution has to be tailored to each firm going through a conscious analysis of its status in the market and its internal situation. In "Using Manufacturing as a Competitive Weapon: the Development of a Manufacturing Strategy" [Beckman, et al, 1990], a five step approach to manufacturing strategy development is presented. This approach can be extrapolated to CE implementation, by using the CE tools to achieve every defined task. The steps are:

1. Start with the business strategy. More specifically, understand why customers will prefer your product or service over your competitor's. Factors that influence the customer's buying decision include: low product cost, high product quality, easy maintainability, prompt product availability, and distinguishing product features.
2. Specify manufacturing's contribution to making customers choose your product instead of your competitor's.
3. Identify manufacturing tactics to execute the strategy (CE tools). This requires understanding how to manage and control the people, processes, materials, and information needed to deliver products in a way that meets the objectives of the strategy.
4. Organize for manufacturing success. Organization design, including structure and performance measurement, must match strategic needs or success will be limited.

5. Measure the results and initiate further change. Strategies must be continually altered to meet the needs of a constantly changing environment. Feedback loops are critical to the continuous improvement process.

It is difficult to give more detailed steps for implementing manufacturing strategies since they depend on each particular case; however, these steps are general actions that, if taken, will facilitate implementation of CE.

**Some Possible Discussion Questions:**

1. What is Engineering?

2. What is a product life cycle? What is the manufacturing life cycle?

3. How do Product Engineering, Process Engineering, and Production Engineering differ from one another? What is the role of each function? What is the role of Engineering Integration?

4. What is Concurrent Engineering? How can it be implemented?

5. What are some of the advantages of CE? What are some possible disadvantages?