1 Introduction

Conceptual design is the thought process of generating and implementing the fundamental ideas that characterize a product or system. This process significantly affects the product novelty, performance, robustness, development time, value, and cost. This chapter presents the framework for the entire design process, within which the upstream stages of studying the need and developing a design concept fit. It concludes with a brief "road map" to the book.

1.1 What Is Conceptual Design?

The core technical concepts developed during conceptual design fundamentally differentiate one product from other competitive products. The degree to which a new product is based on core concepts that are dissimilar from those of existing products determines its level of innovation. Innovative solutions may be viewed as designs that incorporate novel concepts and exceptional functionality. Such solutions can provide companies with a competitive advantage.

Core Technical Concepts of Computer Printers

Ink jet and laser printers serve the same function of producing an image on paper. The ink jet printer transfers small droplets of ink onto the paper, and these droplets form dots, which in turn become the image. On the other hand, the laser printer uses a laser source to trace the image on a drum. When the paper rolls over the drum, the image is transferred onto it. Although both products accomplish the function of applying ink to paper, their core technical concepts are different. This difference results from activities that took place during conceptual design.

To extend this example further, two major technologies (thermal and piezoelectric) are currently in use to inject the ink droplets in ink jet printers. The difference between the ink jet technologies, however, is smaller than that between ink jet and laser printers. Nevertheless, this difference is also the result of the conceptual design stage.

The context in which engineering design activities occur is much larger and more comprehensive than the conceptual design stage. It includes the roles of marketing, finance, planning, and overall management. Furthermore, engineering design is carried out in an integrated and concurrent manner, and requires effective communication and cooperation among the team members. The cooperation of team members is not just cross-functional but may include team members participating within a single functional area. For example, the interaction of team members within the conceptual design stage itself is often quite advantageous as team members build on or play off of the ideas of others. Note that even though designs are often done by teams, in this book we frequently refer to the creator of the product as "the designer."

The task of conceiving of new concepts and their corresponding physical configurations to meet the demands of a market need is not a simple one. In addition to the traditional engineering and scientific disciplines, this complex process involves human cognition, a field regarded as fundamentally outside of the engineer's interest or expertise. How do humans think? How do we create new ideas? What are the cognitive processes involved in a successful conceptual design activity? In spite of these questions and to the relief of most, if not all, of the readers, this book is indeed an engineering text, not a textbook on human cognition.

1.2 Parameter Analysis: A Conceptual Design Methodology

The primary focus of this book is the conceptual design process itself. We present a methodological approach to conceptual design, which we call *parameter analysis.* The development of parameter analysis involved observation of numerous successful and unsuccessful conceptual design processes, attempts to understand the relevant thought processes, and identification of what occurred as these new ideas were created and took shape. Thus, the formulation of the parameter analysis methodology mirrors successful conceptual design activity.

The term "methodology," rather than the term "method," is used purposefully to describe the parameter analysis approach. This may be a somewhat subtle philosophical distinction, but as the authors see it, the word "method" more commonly implies an orderly, step-by-step, prescriptive process with a predictable outcome. "Methodology," on the other hand, is indicative of a process that is based more on a set of general guiding principles than a series of steps. Parameter analysis does indeed describe a set of principles that are important in conceptual design and guides the designer in developing an initial idea into a design. However, through extensive experience in teaching this approach, the authors have discovered that in the early stages of learning parameter analysis, the methodical use of a formal, step-by-step process is very helpful in communicating the principles involved. Thus, this textbook uses somewhat of a "forced march" approach. When the principles are well understood, the extra effort required by such an orderly process is not always necessary.

Just as other textbooks may expand on certain elements of the larger process, this book puts a magnifying glass onto the conceptual design stage. In a sense, one can argue that conceptual design is the most difficult or at least elusive part of the engineering design process since it involves the creation of something new. (The authors recognize that often the insightful recognition of a need is the most crucial contribution to the success of a product, or that it is a clever marketing approach or stunning product aesthetics which will drive a product to the top.) At the risk of overgeneralizing, we contend that parameter analysis is profoundly different from some other approaches to conceptual design, which are more oriented to listing what is already known or searching the state-of-the-art for the best existing solution. Some of these approaches tend to cause the designer to fixate onto existing solutions, thereby hindering innovation. As the reader will see in later chapters, the parameter analysis methodology recognizes the nature of the task and focuses on ways to "unlock the unknown."

One further introductory comment about parameter analysis is in order. As the book will show, a solid understanding of the fundamentals of the physical sciences and engineering disciplines is an important component of parameter analysis. It is often true that the core concept of a clever conceptual design emerges from a thorough understanding of the fundamental physics involved. Thus, there is no substitute for continuous learning of the basics of engineering science. Learning to analyze existing products in a way that uncovers the underlying physics of a configuration is a useful and important by-product of the parameter analysis approach to conceptual design. We call this process *technology observation* and discuss it in Chapter 11. The reader will recognize the linkage between parameter analysis and technology observation in that technology observation essentially represents an effort to discover and learn from the core concepts behind the successful conceptual designs of others.

1.3 Overview of the Engineering Design Process

Numerous terms are used to refer to the process or parts of the process by which products are created, developed, and delivered to the marketplace. Some of these terms are technological innovation, product design, product development, product realization, inven-

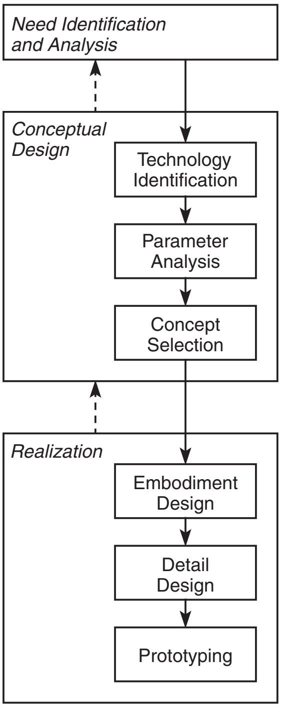

Figure 1.1 Overview of the engineering design process.

tion, and, of course, engineering design. Practitioners and academics often differ on the definitions of these terms. In addition, there are many different models of the engineering design process, but they all include the following elements in some form or another:

- A stage of identifying and analyzing a need prior to initiating conceptual design.
- A conceptual design stage to create new ideas that satisfy the need.
- Activities through which a concept is turned into an overall product or system layout.
- A stage of finalizing the design details.

A high-level view of the engineering design process is represented by the flowchart shown in Fig. 1.1.

The purpose of the upstream stage called *need identification and analysis* is to set the stage for conceptual design. As we will see in this text, the effectiveness of the conceptual design process depends in part on how well a need in the marketplace is understood (analyzed). The two major functions of need identification and analysis can be described in broad terms as:

1. Discovering what the *real* need is, and
2. Analyzing the need such that the best possible solutions to meet its requirements are not precluded by the way the need is understood or described.

In a sense, both the roles of need identification and analysis relate to removing bias from the process. Identifying the *real* need deals with recognizing and removing preconceptions of the need definition. Furthermore, ensuring that the best possible solutions are not inadvertently ruled out of the process is accomplished by analyzing the need in a way in which the influence of preconceived solutions to the problem is objectively removed from the analysis. These two influences on the whole process are inherently quite similar and suppress the natural tendencies of human problem solvers. Therefore, the overt process of ensuring objectivity at this early stage is an essential part of good engineering design practice.

The second stage in the design process is *conceptual design.* The designer will always need a "spark of ingenuity" to come up with innovative initial ideas. These ideas can come from the step we call *technology identification* or from recognizing critical issues during need analysis. One of the strengths of parameter analysis is in providing a systematic methodology to develop an initial, rough idea into a viable conceptual solution. Compared to other approaches, we observe that conceptual designs developed through parameter analysis are considerably more detailed and firm. In the conceptual design stage, the designer typically develops three or more solutions to increase the likelihood of innovation. These solutions are then evaluated against each other to determine which one will be developed further. This stage is known as *concept selection.*

The broadly defined downstream design and development activities identified as *realization* in the simple model of Fig. 1.1 include embodiment design, detail design, and prototyping. These stages may include other functions, such as proof-of-concept testing and design for manufacturing. Although this textbook does not address these downstream design activities, it is vital to recognize that the entire process is not complete until every element of the process has been accomplished.

Notice that the model recognizes that the interfaces between conceptual design and realization, and between need identification and analysis and conceptual design, are bidirectional. That is, it is possible that a conceptual design will be "sent back to the drawing board" or rejected altogether if the results of the downstream efforts reveal issues overlooked during the need analysis and conceptual design stages. In other words, a bad conceptual design cannot become a good design regardless of the quality of the realization effort and may therefore call for additional work. This can cause lengthy delays and increased product development costs, and will eventually have an adverse effect on the success of the product.

1.4 Structure of the Book

This book is heavily dependent on examples to elucidate the methodology presented, and the examples are carefully detailed in a way that clarifies the thought processes undertaken. The student reader is encouraged to study the examples and case studies fully rather than merely read them through rapidly. Furthermore, the student is encouraged to enhance his or her understanding of the methodology by detailing each part of the thinking process in the formal way that is presented in the book. As already mentioned, when the parameter analysis methodology becomes more familiar, the formalism of this approach will be less important. However, successful, high-quality conceptual design comes about through practice and hard work, as well as inspiration. It is often argued that clever, creative conceptual design skills are a gift, not something that can be acquired by learning. However, the authors have seen first-hand the value of the "coaching method" called parameter analysis. Just as an incredibly gifted athlete must practice (with coaching!) to reach the highest level of competitiveness, so, too, can designers benefit from a methodology that sharpens their ability to think in ways that foster creative solutions.

The authors have considerable experience in teaching parameter analysis. This approach to conceptual design has been tested in both graduate and undergraduate design subjects and in numerous industry short courses and projects. The combination of "theoretical" discussion of the principles of parameter analysis and the use of numerous examples and exercises has proved to be an effective way to learn this material.

Chapter 2 introduces a methodology for identifying and analyzing needs as the preparatory step to conceptual design. Chapter 3 presents a detailed example of need analysis to illustrate the formalisms of Chapter 2. While Chapter 4 introduces the parameter analysis methodology, Chapter 5 offers an expanded discussion and provides many guidelines for implementing the methodology. Chapters 6 and 7 are case studies of applying parameter analysis to relatively simple sensor design tasks. Development of alternative conceptual solutions to meet an industrial need is demonstrated in Chapter 8. Chapter 9 shows how parameter analysis was applied to the design of a machine for a novel extrusion process. Chapter 10 contains a comprehensive need identification and analysis, together with the subsequent conceptual design for entry in an engineering students competition. Technology observation is presented in Chapter 11 as an approach that will sharpen the skills of designers by understanding the concepts behind the designs of others. The book concludes with Chapter 12, which provides direction on how to proceed downstream in the design process, and discusses some of the cognitive aspects of parameter analysis.

2

Need Identification and Analysis

Every design process begins by identifying and analyzing the need, and defining it in terms of the design requirements. Clarifying and quantifying the design task helps the designer to gain crucial insights that will facilitate the creation of innovative products. This chapter provides a methodology for carrying out these initial steps. The methodology first calls for identifying the real need in qualitative and solution-independent terms. Next, the overall need is studied in light of five basic categories of functions and constraints: *performance*, *value*, *size*, *safety*, and *special*. These functions and constraints should be fulfilled and satisfied by any design solution that will emerge later in the design process, yet any premature specification of design solutions is carefully avoided during this stage. The need analysis is summarized at the end of the process as a consistent and quantitative set of design requirements.

2.1 The Importance of Need Identification

Design tasks arise from a variety of sources, sometimes referred to as "customers." Because these sources are often nontechnical, the tasks may not be defined in engineering terms. Furthermore, initial task statements sometimes describe *perceived* problems as opposed to *real* needs. The natural tendency of novice designers is to start thinking of solutions that satisfy the perceived problem before gaining full understanding of what should really be designed. This tendency, coupled with a lack of proper definition of the task, may mislead the designer and waste his or her time and effort in solving the wrong problem.

Successful identification and definition of a market need is a prerequisite in developing innovative products. Many companies actively identify new market needs and technologies through market surveys, product benchmarking, technology observation, and forecasting. These activities enable companies to identify immediate, interim, and long-term market needs, as well as current and emerging technologies. Later, during the design process, the designers will focus their efforts on establishing synergy between market needs and existing and new technologies.

An incorrect need definition focuses attention on solution-specific issues, and so the designer will be fixated on developing an apparent solution into a product. In the process, many superior solutions that fit the overall design need better may be overlooked. Competition can leapfrog by better defining the need and conceiving more innovative solutions that match the current technologies with the real need. The importance of recognizing and understanding market needs and matching new technologies with the changing needs of society is illustrated by the following example of the evolution of typewriters.

Market Needs: Insights from the Evolution of Typewriters

The typewriter, a great American invention, shaped our society and the mode of communication for over a century. The origin of typewriters can be traced back to 1868, when C. L. Sholes and several of his associates created the first typewriter prototype. E. Remington and Sons began selling a refined version of this machine in 1874. This typewriter was popularly known as the "blind writer" because the paper was hidden from the typist's view. The character set consisted of uppercase letters only, but an important feature was the arrangement of letters on its keyboard, known as "QWERTY" (the first six letters at the left