1

An Overview

1.1 Introduction

A characteristic feature of modern industrial societies is that new products are appearing at an ever-increasing pace. The drivers for new products are one or more of the following:

Consumers: The requirements and expectations of consumers have been changing – and generally growing – over time.

Technology: The technology is developing with frequent incremental innovations punctuated with less frequent radical innovations. An illustrative example is the increasing number of gates, bits, or transistors in integrated chips over time, as shown in Table 1.1.

Table 1.1. Increasing complexity of integrated chips (adapted from Walsh et al. 2005)

Period	Number of gates, bits, or transistors per device
1947 – 1959	1
1960 – 1966	100 – 1000
1966 – 1970	1000 – 10,000
1970 – 1980	10,000 – 100,000
1980 – 1990	100,000 – 500,000
1990 – 1998	500,000 – 2,000,000
1999 –	2,000,000 and beyond

Societal and regulatory: New legislation to protect consumers and the environment is being enacted at an increasing pace.

Long-term survival and growth requires manufacturing businesses to continuously develop and commercialize new products, or as a minimum, to redevelop current products to better meet consumer requirements as technologies change and improve. New products have a significant impact on sales, revenue, and profits. According to Udell and Baker (1982):

> "On the average, fifty percent of a firm's profits come from products not in its line five years ago. Put another way: In five years, fifty percent of the profits the average business will earn will come from products that do not exist today."

The importance of new products for manufacturing businesses is getting more critical.

New product development is a complicated process and involves the interplay between creativity and management of the process on one hand and the varying needs of potential consumers for the new product on the other hand. The process is costly and the outcomes uncertain. As a proportion of profits, the development of new products is very significant and impacts the bottom line of business as illustrated by the following statement from Takeuchi and Nonaka (1984):

> "At 3M, the multinational company, products less than five years old account for 25% of sales. In 1981 a survey of 700 U.S. companies indicated that new products would account for one-third of all profits in the 1980's, an increase from one-fourth in the 1979's."

The product life cycle, from a marketing perspective, is the period from when a product is launched until it is removed from the market. The product life cycle is roughly 5–7 years for consumer durables and roughly 7–10 years for commercial products. For some high-tech products, the product life cycle is sometimes less than two years.[1]

Not all new product development programmes are a success. The failure can be project related (resulting from cost and/or time limits being exceeded) or due to technical problems (existing technological capabilities being inadequate).[2]

Even when a new product is introduced on the market, the product can fail due to commercial factors such as poor sales, low revenue, and so on. Barclay (1992) reports on a study indicating that the three main causes of product failure are: (i) inadequate market analysis, (ii) product problems or defects, and (iii) too high costs.[3]

Cooper (2003) suggested the following classification scheme for characterizing new product failures.

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[1] In the computer hard disk drive industry, the result of hundreds of millions of dollars and years of effort is a product life cycle that is only one year and a half (Kumar and McCaffrey, 2003).

[2] General Motors, the automobile manufacturer, scrapped the rotary engine project after spending more than 200 million dollars only when it was abundantly clear that it did not have the technology to produce the seals, and the seals could not be developed within a reasonable time (Balachandra, 1984)

[3] A survey by Hopkins and Bailey (1971) reports on the percentage of failures due to a variety of causes. Some of the main causes and the percentage of failures attributed to each cause are as follows:

- Product related
  - Intrinsic: Does not meet performance, reliability, safety or other requirements
  - Extrinsic: Unfavourable reception in market, regulatory change
- Project related
  - Intrinsic: Violating resource constraints (cost, time schedule)
  - Extrinsic: Competitors develop product first

A product is characterized by its properties. Product performance (from a manufacturer, consumer or regulator perspective) is closely linked to the product properties. One of the product properties is *product reliability*. The product reliability and several other properties are dependent on the product specification that forms the basis for development of the product. As a result, product performance and specification are inter-linked and impact on the success of the new product development.

In this book we focus on reliability performance and specification in new product development. We propose a methodology for effective decision making with respect to reliability performance and specification. It is based on the product life cycle and a systems approach that involves the use of models. The goal is to ensure a high probability of success in the new product development process.

In this chapter we discuss some basic concepts and issues needed to get a better appreciation of the scope and focus of the book. The outline of the chapter is as follows: we start with a general discussion of products, properties, and perspectives in Section 1.2. Section 1.3 deals with product reliability and its importance. In Section 1.4 we discuss the product life cycle and indicate the different stages involved. Following this, we discuss product performance and specification in Section 1.5. These set the background to discuss the proposed methodology for making decisions with respect to reliability performance and specification in Section 1.6 and the scope and focus of the book in Section 1.7, respectively. We conclude the chapter with an outline of the book in Section 1.8 where we briefly discuss the contents of the remaining chapters.

1.2 Product Properties and Perspectives

Most products are complex and can be decomposed into several levels with the product being at the top and components at the lowest level. The number of levels needed depends on the complexity of the product.

Inadequate market analysis:	45%
Product problems or defects:	25%
Higher cost than anticipated:	19%
Poor timing of introduction:	14%
Technical or production problem:	12%

(Note: In some cases there is more than one cause for product failure.)

1.2.1 Product Properties: Attributes and Characteristics

Product properties characterize a product. They can be categorized into two groups – internal and external. The internal properties are mainly technical (e.g., the yield stress at which a component fails) and of interest to design engineers. The external properties (e.g., aesthetics, cost of operation) are of greater interest to consumers. Terms such as product features and characteristics are often used instead of product properties. According to Tarasewich and Nair (2000):

> "A distinction can be made between product characteristics and attributes. Product characteristics physically define the product and influence the formation of product attributes; product attributes define consumer perceptions and are more abstract than characteristics."

Note that the internal properties correspond to product characteristics, whereas the external properties correspond to product attributes.

1.2.2 Consumer Perspective

Consumers view a product in terms of its attributes. According to Levitt (1980):

> "To a potential buyer a product is a complex cluster of value satisfactions."

Day et al. (1978) state:

> "Consumers seek benefits rather than products per se."

As a result, we have the following relationship:

$$\text{Attributes (Features)} \rightarrow \text{Bundle of benefits} \rightarrow \text{Value to the customer}$$

A successful new product:

1. satisfies new (or earlier unsatisfied) needs, wants or desires;
2. possesses a performance that is superior in such need satisfactions, compared with other products on the market.

Each new generation of a (successful) product is intended to be an improvement over the existing and earlier ones. Products are getting more complex in order to meet the growing consumer requirements and expectations. As a result, customers need to be assured that the product will perform satisfactorily over the useful life of the product. One way of providing this assurance is through product warranty. This is a service associated with the product. The following statement from *Quality Progress* (1986) illustrates the ranking of different product attributes that customers value:

> The American Society for Quality Control interviewed around 1 000 individuals to determine what attributes were most important to them when selecting a product. A set of predefined attributes were ranked by each customer on a scale from 1 (least important) to 10 (most important). The average scores were:

Attribute	Average score
Performance	9.5
Lasts a long time (*reliability*)	9.0
Service	8.9
Easily repaired (*maintainability*)	8.8
Warranty	8.4
Easy to use	8.3
Appearance	7.7
Brand name	6.3
Packaging/display	5.8
Latest model	5.4

Source: *Quality Progress*, vol. 18 (Nov), pp. 12-17, 1986. Also quoted by Ebeling (1997).

1.2.3 Manufacturer's Perspective

The performance of a new product, from a manufacturer's perspective, can vary depending on the objectives of the business. Barclay (1992) reports a survey that lists many different factors to define a successful new product and percentage of businesses that use the different factors in defining product success. Some factors and associated percentages, according to him are:

Achieving expected profits:	46.6%
Achieving expected market shares:	26.9%
Meeting required quality standards:	19.5%

Another important factor is consumer satisfaction. It affects product sales, since dissatisfied customers might switch to buying a competitor's products and discourage others from buying the product due to negative word-of-mouth effects.

1.3 Product Reliability

Product reliability conveys the concept of dependability, successful operation or performance, and the absence of failures. It is an external property of great interest to both manufacturer and consumer. Unreliability (or lack of reliability) conveys the opposite.

1.3.1 Definition of Reliability

The reliability performance of a product is defined as:

> "The ability of a product to perform required functions, under given environmental and operational conditions and for a stated period of time."
>
> (Adapted from IEC 60050-191, para. 191-02-06).

According to this definition, reliability is a rather vague characterization of the product's ability to perform required functions. Some authors and standards are using the term *dependability* with the same meaning (e.g., see IEC 60300-1).

In many applications, the term reliability is also used as a *measure* of the reliability performance, as "the *probability* that a product will perform one or more specified functions, under given environmental and operational conditions for a stated period of time" (Adapted from IEC 60050-191, para. 191-12-01).

All products degrade with age and/or usage. When the product performance falls below a desired level, then the product is deemed to have failed. Failures occur in an uncertain manner and are influenced by factors such as design, production, installation, operation, and maintenance. In addition, the human factor is also important.

1.3.2 Consequences of Failures

Customer Point of View

When a failure occurs, no matter how benign, its impact is felt. For customers, the consequences of failures may range from mere nuisance value (e.g., failure of the heating of the driver's seat in a car) via serious economic loss (e.g., car engine breakdown) to something resulting in serious damage to the environment and/or loss of life (e.g., critical brake failure in a car). All of these lead to customer dissatisfaction with the product.

When the customer is a business enterprise, failures lead to downtimes and affect the production of goods and services. This in turn affects the goodwill of the clients as well as the bottom line of the balance sheet.

Manufacturer Point of View

Lack of reliability affects the manufacturer in a number of different ways. The first is affect on sales due to negative word-of-mouth effects resulting from customer dissatisfaction. This in turn affects the market share and the manufacturer's reputation. The second is higher warranty costs, resulting from servicing of claims under warranty.

Sometimes, regulatory agencies (e.g., the US Federal Transport Authority) can order the manufacturer to recall a product and replace a component that has not been designed properly from a reliability point of view. In some cases, the manufacturer is required to provide compensation for any damage resulting from failures of the product.

There is no way that a manufacturer can completely avoid product failures. Product reliability is determined by pre-production decisions and impacts the post-production outcomes. The challenge to the manufacturer is to make decisions that achieve a balance between the costs of building-in reliability versus the consequences of the lack of adequate reliability.

1.4 Product Life Cycle

From the manufacturer's perspective, the product life cycle consists of the five phases shown in Figure 1.1. The first three phases (front-end, design, and development) are the pre-production phases and the last two phases are production and post-production.

Figure 1.1. Phases of product life cycle

The front-end deals with new product decisions at the business level. Once a decision is made to proceed with new product development, we move to the design phase. The design phase can be broken into two sub-phases (conceptual and detail design) and similarly, the development and production phases can be broken into two sub-phases (component and product).

The outcome of the development phase is a prototype of the product. If this is suitable for release to the market, then we move to the production phase. The post-production phase consists of marketing the product and providing the post-sale support for products sold.

1.5 Product Performance and Specification

1.5.1 Product Performance

Product performance is a complex entity involving many dimensions and depends on the customer's and manufacturer's perspectives. For each perspective, it is best characterized as a vector of variables, where each variable is a measurable property of the product or its elements.

Desired versus Actual Performance

As the name implies, the desired performance is a statement about which performance is desired from a product, that is, what performance the product should have.

For manufacturers, the desired performance forms the basis for a new product development that will achieve their business goals. For customers, the desired performance defines the expectations in their purchase decisions.

The actual performance is defined as the observed performance of a prototype of a product during development or of a manufactured product over its operating life.

The actual performance will usually differ from the desired performance. The more the actual performance deviates from both the manufacturer's and customers' desired performance, the higher is the probability that the product will not satisfy the manufacturer's and/or customers' expectations.

1.5.2 Product Specification

The product specification forms the basis for building a prototype to ensure that the product achieves the desired performance before production commences. As we proceed through the design phase (from product level to component level), we need to define a hierarchy of more detailed specifications that are linked to the desired performance. A proper understanding of the links between performance and specification is critical in order to ensure the success of the new product.

1.5.3 Performance–Specification Relationships

The specification is derived from the desired performance and depends on the design option selected and the underlying design principles. The predicted performance is derived from the specification using models and data. During the design phase, the data is obtained from engineering handbooks and vendor catalogues and during the development phase, test data is used.

Deriving the specification that will ensure that the predicted performance and the desired performance match, is an iterative process as shown in Figure 1.2. Changes are made to either the specification and/or the desired performance during each iteration cycle. The process stops when we arrive at a specification where the predicted performance matches the desired performance and production can commence.

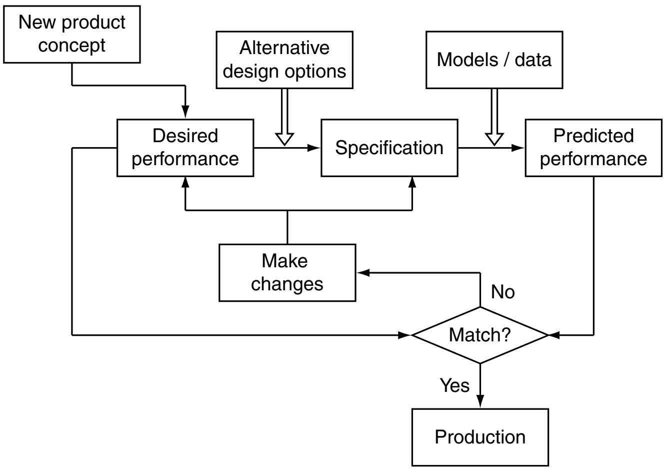

Figure 1.2. Performance – specification relationships

1.6 Reliability Performance and Specification

Reliability performance and specification have not received proper attention in the reliability and the engineering design literature. This is indeed surprising given the importance of product reliability and the consequences of unreliability for both customers and manufacturers.

Deciding on reliability performance and specification for a new product requires solving a variety of problems. Two major problems are as follows:

1. How to obtain the specification given the desired performance?
2. How to obtain the predicted performance given a specification?

In the process, we need to solve a range of sub-problems relating to different phases of the product life cycle. Some of these involve answering "what if?" questions and others to make the optimal choice. A small sample is given below.

- How do warranty period and sale price affect total sales? (Front-end phase)
- How to determine product reliability in terms of component reliability? (Design phase)
- How to assess component reliability based on data (objective and subjective) from different sources? (Development phases)
- How to determine the expected warranty costs? (Post-production phase)
- What is the optimal choice between repair and replacement to minimize the expected warranty cost? (Post-sale phase)
- What is the optimum number of components to be tested during development? (Development phase)

1.6.1 Methodology for Reliability Performance and Specification

A proper methodology for deciding on the reliability performance and specification for a new product requires the following:

1. A product life cycle perspective so that the different reliability issues are linked in an effective manner
2. An integrated framework where the technical aspects (that determine product reliability) and the commercial aspects (dealing with the consequences of lack of adequate reliability) are integrated
3. An effective approach to solve a wide variety of problems

1.6.2 Systems Approach

The systems approach (shown in Figure 1.3) is the most appropriate approach to find solutions to the many relevant problems in reliability performance and specification.

The key feature of the systems approach is the use of models (qualitative as well as quantitative). The building and validation of a model require data and information, and model analysis requires a variety of tools and techniques.[4]

[4] There are many books dealing with the application of the systems approach to solve problems in different disciplines (Roland and Moriarty, 1990; Blanchard and Fabrycky, 1998; Blanchard, 2004).

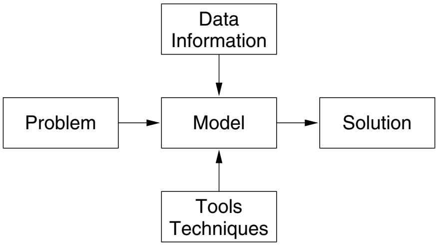

Figure 1.3. Systems approach to problem solving

1.7 Objectives of the Book

The main objectives of the book are as follows:

1. To develop a methodology for deciding on reliability performance and specification for new products
2. Highlight the role and use of models as a tool in solving decision problems
3. Discuss the tools and techniques needed for model building and model analysis
4. Address other issues, such as data collection, management systems, and so on

We focus primarily on the basic concepts and issues and illustrate them through the following two cases.[5]

1.7.1 Case 1 [Cellular Phone]

The term telephone is derived from two Greek words – *tele* (far) and *phone* (sound) – to describe any equipment for conveying sound at a distance. The first telephone was built towards the end of the nineteenth century and the basic principles of a telephone have remained unchanged. The voice vibrates the air, which in turn vibrates a diaphragm. This motion produces a variation in an electric signal. This is transmitted over distance and used to vibrate a diaphragm at the receiving end to reproduce the voice.

Until 1947, the transmission of the electric signal was done using copper cables. In 1947 microwave technology was used for the first time to transmit signals. Both of these required the phone being connected to a transmitter. The cellular telephone first appeared in 1973 and has its own transmitter to send and receive electric signals. This, combined with satellites, implied a seamless transmission of voice as long as the telephone sending the message and the one receiving the message were within geographical range of the communication satellite involved.

Millions of people around the world use cellular phones. A modern cellular phone has an array of functions in addition to sending voice. These include:

- Get information (such as news, entertainment, stock quotes) from the Internet
- Send and receive text mail

[5] Throughout the book we provide references where interested readers can find more details.

- Send or receive e-mails
- Store contact information details
- Alarm clock
- FM radio
- Make task and to-do lists
- Calendar to keep track of appointments and set reminders
- Carry out simple arithmetic calculations
- Games console to play games
- Integrate other devices such as MP3 players, and so on.

The sales (worldwide) have been growing exponentially with 488 million units sold in 2003 and 620 million units in 2004.

1.7.2 Case 2 [Safety Instrumented System]

A safety instrumented system (SIS) is a protection system that is installed to prevent and/or mitigate risk associated with the operation of many types of hazardous systems. A SIS generally consists of one or more input elements (e.g., sensors, transmitters), one or more logic solvers (e.g., programmable logic controllers, computers, relay logic systems), and one or more final elements (e.g., safety valves, circuit breakers). The main elements of a SIS are illustrated in Figure 1.4.

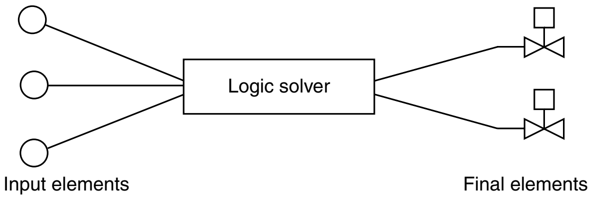

Figure 1.4. Sketch of a simple safety instrumented system (SIS)

SISs are used in many sectors of modern society, for example, as emergency shutdown systems in chemical plants, fire and gas detection and alarm systems, pressure protection systems, dynamic positioning systems for ships and offshore petroleum platforms, automatic train stop systems, anti-lock brakes in automobiles, and systems for interlocking and controlling the exposure dose of medical radiotherapy machines.

The main functions of a SIS are:

- When a predefined process demand (deviation) occurs, the deviation shall be detected by the SIS input elements, and the required final elements shall be activated and fulfil their intended functions.
- The SIS shall not be activated spuriously, that is, without the presence of a predefined process demand (deviation) in the system.

A failure to perform the first system function is called a *fail to function*, and the failure of the second function is called a *spurious trip*.

Safety and reliability requirements for the SIS functions are given in the international standard IEC 61508 and related standards. IEC 61508 is a performance-based, generic standard that covers most safety aspects of a SIS.

1.8 Outline of the Book

The book has 11 chapters. A brief summary of the chapters is as follows:

Chapter 1, An Overview: This chapter deals with the importance of product performance and specifications in the context of new product development. The scope and focus (on reliability performance and specifications) of the book are described and an outline of the structure of the book is given. The two illustrative cases that will be used throughout the book are presented.

Chapter 2, New Product Development: The chapter starts with a general discussion of products and then looks at the new product development process and discusses different models proposed in the literature. Following this, it outlines the two-stage, three-level model that is used in later chapters.

Chapter 3, Product Performance and Specification: There are many different notions of product performance and of production specification. The chapter critically reviews the literature, defines the notion that is used in this book, and discusses the relationships between the two. It then develops a hierarchy of performance and specifications based on the model in Chapter 2. It concludes with a methodology for making decisions with regard to performance and specification. This involves the use of models. The data requirements and the tools and techniques needed for decision making are also discussed.

Chapter 4, An Introduction to Reliability Theory: Reliability theory deals with the interdisciplinary use of probability, statistics, and stochastic modelling, combined with engineering insight into the design, and the scientific understanding of the failure mechanisms, to study the various aspects of reliability. As such, it encompasses issues such as (i) reliability modelling, (ii) reliability analysis and optimization, (iii) reliability engineering, (iv) reliability science, (v) reliability technology and (vi) reliability management. All of these are important in the context of reliability performance and specification. The chapter discusses the important concepts and issues that are needed for later chapters.

Chapter 5, Performance and Specification in the Front-end Phase: Product performance from the business perspective is the starting point of a new product development process. This issue is discussed for different kinds of products. It then looks at translating this into alternative sets of product specifications (which define product attributes and features), the technical and commercial implications and to evaluate the economic viability. Product reliability is not addressed explicitly, but the implications of it on the technical and commercial aspects need to be addressed at this phase. Once this is met, the specification is passed on to the design group to come up with designs to produce the product. The chapter deals with models, data and, tools and techniques needed to derive the specifications and to evaluate the implications for the business and the economic viability.

Chapter 6, Performance and Specification during Design: The design process involves two sub-phases – conceptual and detailed design. For the conceptual phase, the specification from the front-end phase defines the desired performance. The design group looks at alternative design architectures and their technical and economic implications. If the outcome is favourable, we proceed to the detailed design. In both these phases, the aim is to translate the desired performances (at various sub-levels) into specifications with the specification at a sub-level being linked to performance at the sub-level above it. The reliability issues include reliability allocation, reliability improvement (through development and/or redundancy), maintenance and maintainability. The chapter discusses a variety of reliability related decision problems using a format similar to Chapter 5. The final outcome of the design process is a specification at the lowest level and is used in the fabrication of the product.

Chapter 7, Performance during Development: The development phase involves development at component and at system level. At component level, we may test the actual component reliability performance. If this falls below the desired value, then we need to carry out programmes to improve the reliability. One such is the test-analyse-and-fix (TAAF) programme where products are tested to failure and through a root cause analysis a solution is found to avoid the failure and thus improve the reliability. At the system level, we assess the actual performance of the final prototype through testing. Often, tests are carried out to assess the performance under different environments, the limits of the actual performance, and so on. In addition, we need to carry out tests in accelerated mode so as to reduce the development time. The reliability issues include optimal design of experiments for assessing reliability, planning of accelerated tests, and statistical methods for reliability assessment. The chapter deals with these issues in the context of assessing the actual reliability performance. The focus is on the models needed for designing tests, data collection issues, tools and techniques for data analysis, and models to assess and/or predict actual performance.

Chapter 8, Product Performance and Production: The actual performance of products produced in large numbers will differ from the actual performance of the prototype in the development phase. This is because of quality variations in the inputs (e.g., material, components bought from vendors) and variations in the production process. The chapter looks at the effect of these factors on the performance and techniques to control and/or minimize their effects. The issues include acceptance sampling of components so that the components meet the required reliability specification and assessing reliability variations during production. The techniques for data analysis to assess actual performance are similar to those in Chapter 7.

Chapter 9, Post-sale Performance: The actual performance in the post-sale phase will differ from that during the production phase due to variability in the external factors, such as, usage environment, usage intensity, maintenance, and so on. The main source of information (for consumer durables) is the claims under warranty. Here again, the focus is on assessing actual performance based on the warranty data and other information. The chapter deals with this topic and the comparison between the actual and the desired performance at the business level, and the implications for changes to product specifications. The reliability issues include warranty cost analysis, data collection, decision making for improvements, and so forth. The chapter also deals with issues such as product recall and warranty logistics.

Chapter 10, Product Safety Requirements: Many products may cause health problems, injuries and/or pollution of the environment. The problems may occur during normal use of the product, transport, cleaning and maintenance, and also due to misuse of the product. Problems caused by product failures may, to some degree, be prevented or mitigated by using the procedures in the previous chapters of this book. Several other hazards are not covered by these procedures, and need to be addressed in separate programmes. The chapter outlines an approach to product safety that can be integrated with the reliability programme. The product safety programme is compatible with the European safety directives, especially the Machinery Safety Directive.

Chapter 11, Reliability Management System: Decisions with regards reliability performance and specification require the linking of decision making at the different stages of the product life cycle. This must be done in an integrated manner. A management system is needed for carrying this out and this topic is addressed in this chapter. The key elements of the management system are: (i) a data collection system, (ii) a package of tools and techniques for data analysis and for model building, analysis and optimization, and (iii) a user interface to assist the manufacturer in making effective decisions. The chapter discusses the issues associated with the collection and analysis of reliability related data.