2

Products and Product Quality

2.1 Introduction

Products affect each and every one of us every day of our lives. We use them in many different ways and for many purposes, ranging from eating, wearing and medication, to communication, transport, and energy production, and we are often totally dependent on them. Products are continuously evolving, with new ones replacing earlier ones, thus defining a product life cycle. The rate at which new products have been appearing on the market has been expanding at an exponential rate and the cycle times are becoming shorter. In order to survive and grow in such an environment, manufacturers must continuously produce new products with improved quality. In this chapter, we deal with products and product quality issues.

The outline of the chapter is as follows. In Section 2.2 we look at product classification, decomposition and the bundling of product and service. Section 2.3 deals with product quality and briefly reviews different definitions and notions of quality. An important topic of focus in this section is the connection between product quality and customer satisfaction. Section 2.4 introduces the notion of a product life cycle from the manufacturer and buyer perspectives. The former is used extensively in later chapters. Reliability is one of the quality dimensions and of great importance in the context of warranty costs. This topic is discussed in Section 2.5.

2.2 Products

A narrow definition of products is that they are physical and tangible. This is in contrast to services, which are intangible. The distinction between products (as defined above) and services is becoming blurred and a more commonly accepted definition is that a product generally involves combinations of the tangible and the intangible, for example:

A product can be tangible (e.g. assemblies or processed materials) or intangible (e.g., knowledge or concepts), or a combination thereof. A product can be either intended (e.g., offering to customers) or unintended (e.g., pollutant or unwanted effects).[1]

2.2.1 Product Classification

Broadly speaking, products can be categorized into the following four groups:

- **Consumer non-durables**: These are consumed by society at large and include items such as processed food, cosmetics etc. In general these are inexpensive items and often not covered by warranty. However, various health and safety standards cover such items and provide protection to consumers.
- **Consumer durables:** Society at large, as well as commercial enterprises and government agencies are all users of consumer durables (e.g., computers, television sets, furniture, appliances, automobiles), and there are typically many manufacturers competing in the marketplace. Thus this group may be characterized by the large number of consumers for, and manufacturers of, the product. The complexity of the products in this group can vary considerably.
- **Industrial and commercial products:** Industrial and commercial products (e.g., large-scale computers, cutting tools, pumps, X-ray machines, commercial aircraft, hydraulic presses) are characterized by a relatively small number of consumers and manufacturers. The technical complexity of such products and the mode of usage can vary considerably. The products can be either complete units such as aircraft, trucks, pumps, and so forth, or product components needed by a manufacturer, such as large storage batteries, commercial drill bits, electronic modules, turbines, etc.
- **Specialized defense-related and industrial products:** Specialized defense products (for example, military aircraft, ships, rockets) are characterized by one or more consumers (for example, several countries) and a relatively small number of manufacturers. The products are usually complex and expensive and involve "state-of-art" technology with considerable research and development effort required of the manufacturers. Still more complex are large systems (for example, power stations, computer networks, communication networks, and chemical plants) that are collections of several inter-linked products. These are specialized industrial products.

Another classification of products is as follows:

- **Standard products:** These are manufactured in anticipation of a subsequent demand. As such, these products are manufactured based on

[1] See ISO9000 [1].

previous experience and the results of market surveys. Products of this type include all consumer durables and most commercial and industrial products.

- **Custom-built products:** These are manufactured in response to a specific request from a customer. Specialized defense and industrial products would be in this category, as would commercial products such as some aircraft, luxury items, and so forth.

Example 2.1 [Photocopier]

The modern photocopier is one of the most common and important pieces of office equipment in the modern workplace and can be found in many homes for personal use as well. The development of the photocopier can be traced back to the early 1800s. The earliest versions were the projection copiers. These included a copy camera and a photostat machine. The copy camera took a photograph of the original negative. The film was then developed using liquid chemicals. This converted the negative into a positive copy that could be either smaller or bigger than the original. A photostat machine operates like a printing machine with the original being a stencil that is coated with ink (a chemical liquid) and then printed on a paper.

The transition from a wet to a dry process was a major technological breakthrough. The dry process was invented in 1938 by Chester F. Carlson (an American physicist) and involved electrostatic photocopying. This type of photocopying is known as “xerography” (a word derived from two Greek words – “xeros” meaning dry and “graphy” meaning writing).

Photocopiers have been continuously evolving and modern versions act as printers for computers and have sophisticated logic built in to do several tasks. There are many manufacturers of photocopiers. Xerox, Canon, Kodak, Mita, Ricoh, Toshiba are few of the well-known brands.

In the USA the sales and rentals of photocopiers has been growing steadily and the revenue generated, at the industry level, is shown in Table 2.1. The total number of units sold in 1999 was 907,470.

Table 2.1. Revenues in the US copier industry (in billion dollars)

Year	1984	1989	1994
Sales	3.9	4.7	4.6
Rentals	3.3	3.8	4.6
Service	3.1	5.4	5.8
Supplies	3.0	4.3	4.9

The process of xerography involves the following steps: [2]

1. The clean surface of a “photoreceptor” drum (or belt) is coated with a light sensitive (photo-conductive) material that acts as an insulator in the dark and as a conductor when exposed to light.

[2] For more details, see http://www.physics.uoguelph.ca/summer/scor/articles/scor54.htm and Bruce and Hunt [2].

2. The photoreceptor material is electrically charged positively through a "corona wire".
3. Light is reflected from the original through a lens on to the drum.
4. The light dissipates the charge on the drum in the areas of the image that are blank. A positively charged image then forms on the light sensitive surface.
5. The negatively charged "toner" (also referred to as "dry ink") is dusted on the drum and sticks to the positively charged image on the drum. This leaves a "toner image" of the original on the drum.
6. A paper charged positively with the corona wire is pressed against the drum so that the toner image is transferred.
7. The "fuser" heats the positively charged paper for a short period so that the toner is permanently attached to the paper.
8. The drum surface is cleaned by "cleaning blade" to remove the remainder of the toner and transferred into a waste bin so that the process can be repeated.

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Example 2.2 [Automobile]
The automobile is a self-propelled passenger vehicle designed to operate on ordinary roads. The earliest automobile had a steam driven engine and was produced in 1769. The earliest gasoline car appeared in 1855 and since then it has gone through many technical innovations.

Automobiles can be classified into several types based on (i) structure and usage – passenger cars (PC), light trucks (LT), vans, buses, etc., and (ii) the primary energy source – petrol, diesel, electric, hybrid (combinations of petrol and electric) and others such as hydrogen, solar, etc., which are still in the experimental stages. The underlying principle of the gasoline-powered automobile is fairly simple. The chemical energy in fuel (petrol or diesel) is released through combustion in the cylinders of the engine and transmitted to the wheels through a transmission system to achieve the desired motion. In the case of an electric automobile, energy stored in a battery is used to run an electric motor and this in turn is transmitted to the wheels.

Mass production of automobiles started in the early part of the twentieth century with the Model T produced by Ford. Since then, the automotive industry has grown significantly in the USA and many other countries and has a significant impact on the national and global economies. In the USA, the big three companies (General Motors (GM), Ford and Daimler-Chrysler) reported total revenues of over 49, 41 and 18 billion dollars, respectively, for the first quarter of 2003. The automobile has affected the life styles and the social fabric of industrial societies.[3]

The annual unit sales of passenger cars in the USA for the big three (GM, Ford and Chrysler) and others (primarily imports) over the period 1981–2002 are shown

[3] There are several books that deal with the economic and social impacts of the automobile. See, for example, Rae [3] and Flink [4].

in Table 2.2. A plot of the annual sales of passenger cars (PC) and light trucks (LT) is shown in Figure 2.1.[4]

Table 2.2. Annual sales of automobiles in the USA (thousands)

	Manufacturer				
Year	**Chrysler**	**Ford**	**GM**	**Others**	**Total**
1981	841	1,413	3,797	2,464	8,515
1982	794	1,346	3,516	2,300	7,956
1983	951	1,571	4,054	3,973	9,149
1984	1,079	1,979	4,601	2,665	10,324
1985	1,245	2,079	4,693	2,962	10,979
1986	1,309	2,081	4,693	3,321	11,404
1987	1,096	2,061	3,728	3,302	10,187
1988	1,191	2,290	3,822	3,240	10,543
1989	1,020	2,178	3,437	3,142	9,777
1990	861	1,936	3,309	3,194	9,300
1991	703	1,636	2,909	2,927	8,175
1992	680	1,778	2,844	2,911	8,213
1993	834	1,964	2,927	2,793	8,518
1994	812	2,036	3,080	3,063	8,991
1995	786	1,898	2,956	2,995	8,635
1996	833	1,844	2,786	3,063	8,526
1997	737	1,720	2,689	3,126	8,272
1998	739	1,660	2,456	3,287	8,142
1999	745	1,733	2,591	3,629	8,698
2000	649	1,687	2,532	3,979	8,847
2001	558	1,495	2,272	4,098	8,423
2002	527	1,326	2,069	4,181	8,103

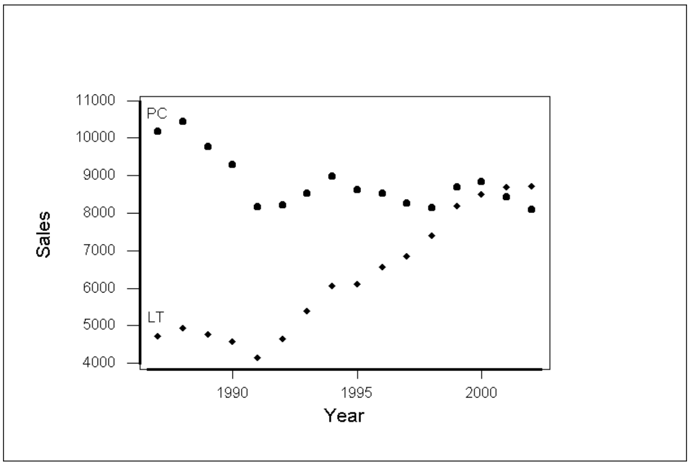

Figure 2.1. Vehicle sales (thousands), by type (1987–2002)

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[4] The data are from Ward's Communications [5].

2.2.2 Product Decomposition

A product can be viewed as a system that consists of several elements and that can be decomposed into a hierarchy of levels, with the system at the top level and parts at the lowest level. There are many ways of describing this hierarchy. The following seven-level description would provide a detailed breakdown:

Level	**Characterization**
0	System
1	Sub-system
2	Major assembly
3	Assembly
4	Sub-assembly
5	Component
6	Part

Such detailed product characterizations are often necessary because of the increasing complexity of products, due mainly to technological advances. The common farm tractor illustrates this growth in product complexity [6]:

Model year	1935	1960	1970	1980	1990
Number of components	1200	1250	2400	2600	2900

For more complex products, the number of parts may be orders of magnitude larger. The success of the Mariner/Mars spacecraft required the satisfactory performance of some 138,000 components over the nine months of its mission in space [7]. The Boeing 747 has 4.5 million parts [8]. Other very large systems in terms of parts counts are the space shuttle and its launch system, large naval ships such as aircraft carriers, telecommunications systems, and so forth.

Example 2.3 [Photocopier]

The modern photocopier is a complex system consisting of a large number of components. These can be grouped into several sub-systems as follows:

1. Drum: surface
2. Optical: lens, lamp, mirror
3. Electro and chemical: corona wire, toner
4. Heating: fuser
5. Mechanical: feed mechanisms, cleaning arm
6. Electronic control: to perform various control tasks
7. Diagnostics: to detect problems and display on the front panel
8. Environment related: ozone filter, waste bin

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Example 2.4 [Automobile]
The modern automobile is a complex system comprising of over 15,000 components and can be decomposed into the following sub-systems:[5]

1. Body (passenger compartment)
2. Engine (power source)
3. Chassis (for supporting engine and body)
4. Transmission (for transmitting power from engine to the wheels through shafts and gears)
5. Controls (for accelerating, braking, steering, etc.)
6. Cooling (for cooling the engine, providing comfort to passengers)
7. Electrical (battery, starting motor, lights, logic controllers)
8. Safety (seat belts, air bags, locks)
9. Lubrication
10. Fuel (tank, carburetor, filters, fuel lines)
11. Exhaust system (muffler, catalytic converter)
12. Others (seats, doors, windows, radio, etc.)

Each of these in turn can be decomposed into assemblies, sub-assemblies, and so forth, down to the part level. The components for some of the sub-systems are as follows:
Engine: cylinder block, cylinder head(s), pistons rings, connecting rod, bearings, crankshaft main bearings, camshaft bearings, cam followers, timing chain or belt; timing gears, guides, rocker arms, rocker shaft, rocker bushings, cylinder head valves, valve guides, valve lifters, valve springs, valve seals, valve retainers, valve seats, push rods, water pump, oil pump and oil pump housing, oil pan, intake and exhaust manifolds, valve covers, engine mounts, turbocharger/supercharger housing seals and gaskets
Transmission (Automatic or Standard): transmission case, torque converter, electronic shift control unit, transmission cooler, oil pan; seals and gaskets
Cooling: engine cooling fan and motor, fan clutch, belt, radiator, heater core, thermostat, blower motor, hot water valve
Electrical: alternator, voltage regulator, starter motor, starter solenoid and starter drive, engine compartment wiring harness, computerized timing control unit, electronic ignition module, crank angle sensor, knock sensor, ignition switch, ignition switch lock cylinder, front and rear window wiper motors, washer pump and switch, stop lamp switch, headlamp switch, turn signal switch, heater/air conditioner blower speed switch, manual heater/air conditioner control assembly, and horns
Fuel Delivery: fuel pump, fuel injection pump and injectors, vacuum pump, fuel tank, fuel tank sending unit, metal fuel delivery lines.

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[5] See http://auto.howstuffworks.com for a discussion of the principles of how these sub-systems work.

2.2.3 Perspectives

One can look at a product from many different perspectives. For our purposes, the key considerations are:

- **Business**: From the business viewpoint, the focus is on the impact of the product on overall business performance.
- **Technical**: The technical aspects deal with the engineering of the product. Here the focus is on technical issues that ensure that the product has the desired characteristics and attributes.
- **Commercial**: The commercial aspects deal with issues such as promotion, sales, pricing, revenue and costs.
- **Customer**: Product-related issues viewed from the customer perspective include cost, operation, maintenance, reliability, useful life, and so forth.
- **Environmental**: Issues dealing with the environmental impact of the new product are of great importance in the context of "green" movements that advocate "environmentally friendly" products and the support for these movements is increasing around the world.
- **Safety and Regulatory**: All products must meet certain requirements regarding safety when used in the intended mode of operation. Failure to do so can result in accidents that can lead to environmental damage, loss of life and economic costs. Most products need to conform to international, national or industry standards.

2.2.4 Product Service Bundling

When making product purchases, customers believe that they are buying more than a physical item. They also have expectation about the level of support service subsequent to the sale of the product. As a result, customers tend to combine product and service attributes together as part of a total package to which they attach some individual perceived value. Most products fall somewhere between pure product and pure service. Manufacturers need to decide which attributes or tangibles are more important than others according to the needs of their customers.

Product support includes installation, documentation, maintenance and repair services (also called field service), user training, and equipment upgrading. Good product support plays a key role in ensuring high customer satisfaction. A majority of dealers for simple domestic appliances perceive product service as a selling point, and good field service can give a competitive edge to technology firms. The importance of post-sale activities in the context of product choice has received a good deal of attention in the literature.[6] Product support service can add value to the tangible product in several ways. Examples of factors that add value to the product from the customer's perspective are:

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[6] See for example, Lele [9], Lele and Karmarkar [10], Ives and Vitale [11 and 12], and Ritchken, Chandramohan and Tapieor [13]. For a discussion of customer support during the design stage of a new product to ensure high customer satisfaction, see Goffin [14].

- Prompt and proper delivery and installation
- Extending the life of the product
- Direct value in the initial sale and subsequent re-sales
- Comprehensive warranty coverage.

Some of these factors are related. For example, the re-sale value of a used automobile may drop significantly once the warranty expires.

Product support (providing spare parts, extended warranties or service contracts) has a higher profit margin (typically around 30%) as opposed to selling products (typically around 10%) [15]. This implies that product support is a source of significant revenue if manufacturers manage it properly. The product support market (comprised of both the original equipment manufacturer and third parties offering support) has grown at a rate more than 15% during the 1990s.

2.3 Product Quality

Product quality is difficult to define since there are several different notions associated with the concept. A dictionary definition for (product) quality is as follows [16]:

> *Relative nature or kind, distinguishing character; a distinctive property or attribute, that which gives individuality; particular capacity, value or function; particular efficacy, degree of excellence.*

According to the International Standardization Organization [1],

> *Product quality is the totality of features and characteristics of a product that satisfies the stated or implied needs.*

2.3.1 Perspectives

The two important perspectives on quality are those of (i) the manufacturer and (ii) the customer. Manufacturers' criteria may be summarized as "criteria that describe what the manufacturer put into the product," while customers' criteria are "criteria that describe what the consumer gets from the product". As a result, there are several different definitions and notions of product quality.

2.3.2 Definitions of Quality

Five definitions of quality are as follows [17]:

- **Transcendent**: This is synonymous with "innate excellence" and quality indicates an expression of excellence. It is viewed as neither mind nor matter but something different which is difficult to define but easy to recognize.

- **Product-based**: Product quality refers to the various attributes, features or characteristics that are intrinsic to the product. It is an objective, measurable variable, which can be described in terms of technical specifications.
- **User-based**: This is based on the notion that quality "lies in the eye of the beholder" and is very subjective.
- **Manufacturing-based**: Here quality is defined in terms of the product's ability to meet the stated specifications. Greater conformance to the specifications implies quality. Any deviations from specifications would indicate depreciation in quality. The level of conformance depends on the design of the product and the materials and processes used in its production.
- **Value-based**: The concept of value has its roots in the microeconomic tradition. Here the quality of a product is determined in relation to its price and not solely by its own merits.

2.3.3 Notions of Quality

Several different dimensions of product quality have been defined. Reliability is of special importance in the context of product warranty and will be discussed in more detail later in the chapter. We discuss briefly some other notions that are of relevance in the context of warranty management.[7]

- **Performance**: Product performance can be described as the response of a product to external actions in its working environment. This consists, in general, of a multi-dimensional set of variables, each of which is *a measurable property of a product or its elements*. The performance of an item is defined in terms of its functional properties, for example, power, throughput, fuel consumption, etc., in the case of an engine. Product performance is realized through the performance of its constituent components.
- **Conformance**: Due to variability in manufacturing, items produced are not all identical. As a result, the performance of items can vary. Conformance can be defined as the degree to which the performance of an item varies from a pre-specified performance standard. This is the most common accepted notion associated with conformance (or more correctly, with non-conformance). Conformance can be defined as the degree to which a product's design and operating characteristics meet pre-established standards. This definition is broader and includes conformance of the product design to some industry, national, or international standards. The occurrence of nonconforming items is affected by process capability and can be controlled through effective quality control strategies.
- **Durability**: Product durability is a measure of product life. All products deteriorate and degrade with time and/or usage. This can be controlled to

[7] For more on the definition and dimensions of quality, see Chapter 1 of Evans and Lindsay [18].

some extent through proper maintenance. Irrespective of this, the deterioration continues, resulting in the useful life of the product eventually coming to an end.

- **Serviceability**: Serviceability relates to the ease and speed with which a failed item can be restored back to its working state. As such, it is linked to repairability of the product and deals with duration and cost of repairs. Two types of service actions are encountered: (i) anticipated services requiring planning on the part of the buyer (dealing with issues such as installation, training, written instructions, maintenance, and upgrading) and (ii) unanticipated services (dealing with issues such as corrective maintenance to fix failures).
- **Perceived Quality**: Perceived quality is a result of the consumer's (the buyer's) subjective assessment of the quality of a given product. Perceived quality thus differs from objective quality. Objective quality depends on the technical and functional specifications of a product. Subjective quality, on the other hand, is linked to the consumer and her/his perception of the quality of a product.

2.3.4 Product Quality and Customer Satisfaction

From the manufacturer’s point of view, customer satisfaction is very important, as indicated by the following statement [19]:

> *Customer satisfaction is definitely essential to survival in today’s global dynamic competition and everybody knows that the ultimate proof of a product design is the acceptance by the customer. As a result of open market place, only those companies that listen to what the customer wants and provide high-quality and reliable products, which meet customer expectations, over the product useful life period with minimum cost in a timely fashion will eventually survive.*

As a result, manufacturers are forced to offer every possible value-added service in order to achieve customer satisfaction and retain those customers who already do business with them. In order to satisfy the consumer, the product and any associated services must meet or exceed his/her expectations and needs.

High customer satisfaction is important for:

- Repeat sales
- Positive word-of-mouth promotion
- Customer loyalty.

A customer is satisfied when his/her perception of the ratio of benefits (from the product and associated services) to the costs paid to obtain the benefits are met or exceeded. This involves (i) perceived product quality, (ii) value-based notion of quality, and (iii) perceived service quality. The benefits customers expect depend primarily on how they perceive product and service quality, and whether or not their perceptions are valid. Customers often tend to use limited knowledge of product and tangible service attributes to assess quality, as many dimensions of quality cannot be observed directly in most cases.

For most products, the product and service attributes can be grouped into two categories: (i) "hygiene" factors and (ii) "satisfiers" or "motivators".[8] Customers expect minimum levels for the hygiene factors (for example, spare parts, service centers). The lack of this level results in dissatisfaction. Any hygiene factors done in excess to what the customers expect will not increase the expected benefits to customers. The satisfiers are those attributes (for example, good service, free consulting) that go beyond the customer's expectations and enable a firm to gain and create a competitive advantage. These go beyond the expected levels of performance and add unexpected value to the bundle of attributes offered to the customer.

If a firm does not provide an adequate number of hygiene factors, this will result in dissatisfied customers. However, having an adequate number of hygiene factors does not help to create customer satisfaction. A firm creates customer satisfaction by using satisfiers. A manufacturer not providing good post-sale service leads to customer dissatisfaction. In this sense it is a hygiene factor.

Customer satisfaction is different from customer loyalty.[9] A satisfied customer will shop anywhere. Satisfaction does not give any indication that the customer will repeat a purchase. A loyal customer is a satisfied customer who not only continues to be loyal in terms of repeat purchases, but also proactively promotes the product through word-of-mouth. In the automobile industry, in which 85% to 95% of the customers reported that they felt satisfied, only 30% to 40% return to buy the same make or model of car [22]. Loyalty can be viewed as the highest form of customer satisfaction.

In order to ensure a high level of customer satisfaction, manufacturers must have a quality product. Without a quality product or service, there is no chance to achieve satisfaction.

For consumer durables, customer satisfaction and customers' perception of product quality is a complicated issue. Different individuals may have different views on a product's quality for the same product. A customer's perception of a product's external properties may be the result of cultural background (e.g., different cultures have different views on aesthetics), on physical and cognitive capabilities (cognitive capabilities determine, for example, how easy it is for a customer to operate a product), on individual experiences and preferences (a customer having had a bad experience with a manufacturer's product will consider another manufacturer), and on basic functional needs (which can vary from one to another). In order to produce a product that meets customer expectations, the manufacturer needs to ensure that these are well understood and properly defined. Often, customer expectations are expressed as vague statements. This is particularly true for consumer durables.

Example 2.5 [Automobile]

The following is a list of customers' comments on what constitutes a reliable automobile [23]:

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[8] This was first proposed by Nauman and Jackson [20].

[9] This topic is dealt with in some detail by Gitmore [21].

- Last for a long time
- Starts every morning
- A well-made car
- No breakdown
- Consistent performance
- Hassle-free during ownership
- Dependable
- Maintenance free.

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Customer satisfaction in the context of industrial products is different from that of consumer durables. For consumer durables, the individual consumer is the unit of analysis for satisfaction. In business-to-business transactions, the customer is no longer a passive buyer but an active partner, and the relationship between the customer and manufacturer is long-term in nature and complex.[10]

2.4 Product Life Cycle

New products are appearing on the market at an ever-increasing pace, mainly as replacements for existing products. This leads to the concept of product life cycle. There are a number of approaches to this concept. The concept is quite different in meaning, intent and importance for buyer and manufacturer. For each, there are different life cycles that may be of interest. Note that the product life cycle can be viewed in a larger overall context, with important strategic implications. In this structure, the product life cycle is seen as embedded in the product line life cycle, which, in turn, is embedded in the technology life cycle.

2.4.1 Manufacturer's Point of View

We consider two approaches, the first based on a marketing perspective and the second on a production perspective. From the marketing perspective, the product life cycle is defined as the curve that represents the unit sales for some product extending from the time it is first entered into the marketplace until it is removed. In this traditional form, the product life cycle describes sales over time and is usually characterized in terms of the following four phases:

- **Phase 1**: Introduction phase (with low sales),
- **Phase 2**: Growth phase (with rapid increase in sales),
- **Phase 3**: Maturity phase (with near constant sales), and
- **Phase 4**: Decline phase (with decreasing sales).

A typical plot of the life cycle is shown in Figure 2.2.

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[10] Customer satisfaction in the context of industrial products has received very little attention relative to that for consumer products. For a more detailed overview of customer satisfaction for consumer products, see Oliver [24] and Homburg and Rudolph [25].

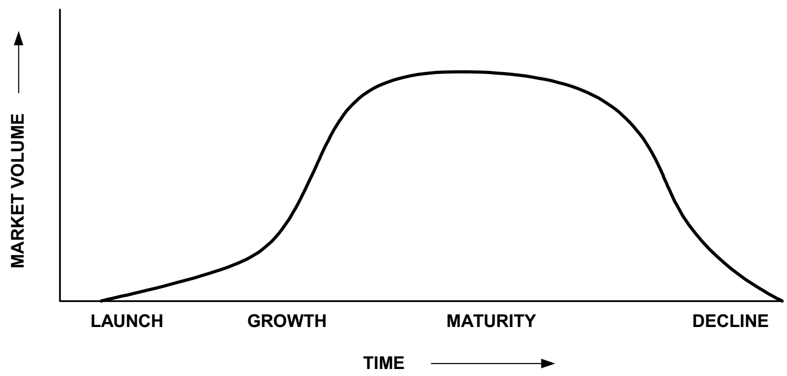

Figure 2.2. Product life cycle

From a production perspective, the product life cycle is the time from the initial conception of the product to the final withdrawal of the product from the marketplace. It can be broken into two stages – pre-launch (comprising of three phases) and post-launch (comprising of two phases). As the name implies, the pre-launch stage deals with activities undertaken by the manufacturer prior to the release of the product in the marketplace. The five phases occur sequentially and are as follows:

- **Phase 1** [Front-end]: Evaluation of an initial product idea, identification of target characteristics and pricing, and a feasibility study leading to a go/no-go decision.
- **Phase 2** [Design and development]: Development of non-physical product solutions and construction of a prototype.
- **Phase 3** [Production]: Coordination of materials, processes and other resources necessary to produce the product.
- **Phase 4** [Marketing]: Distribution and promotion.
- **Phase 5**: [Post-sale servicing] All the activities needed to ensure satisfactory performance of the product over its useful life.

Note that the marketing phase can be divided into four sub-phases, as indicated above.

2.4.2 Buyer's Point of View

From the buyer's viewpoint, the product life cycle is the time from the purchase of an item to its discarding at the end of its useful life or its replacement for any of a number of reasons (obsolescence, maintenance cost, lack of efficiency, etc.). The life cycle for the buyer involves three phases, namely

- **Phase 1**: Acquisition,

- **Phase 2**: Operation and maintenance, and
- **Phase 3**: Discard and replacement by new one.

2.4.3 Product Performance

Here we consider the product life cycle from the production perspective. The first two phases constitute the pre-launch stage, and the last three phases, the post-launch stage. In this structure, three notions of product performance are useful: (i) desired performance, (ii) predicted performance, and (iii) actual performance. These are indicated in Figure 2.3 and discussed below. They are of particular importance in the context of new product development.

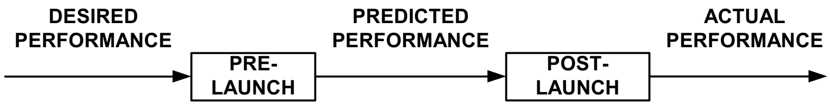

Figure 2.3. Performance and product life cycle

- **Desired performance** may be defined as *a statement about which performance is desired from an object, i.e. stating what performance an object 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 manufacturer's main challenge lies in realizing a product that is as much in accordance with the customers' desired performance as possible, but that also meets the manufacturer's business goals (such as total sales, profits, etc.). The degree to which the manufacturer succeeds in fulfilling these expectations determines the customer satisfaction. Desired performance may be defined as a range, a minimum or maximum value, or an absolute value.
- **Predicted performance** may be defined as *an estimate of an object's performance, attained through analyses, simulation, testing, etc.* The manufacturer uses predicted performance throughout design, development and production, to evaluate whether a product will meet performance goals. This forms the basis for decisions during the various phases of the product life cycle.
- **Actual performance** may be defined as *observed performance of a prototype of an object during development or over its operating life*. Actual performance will differ from the desired performance. The more the actual and desired performances differ, the greater is the probability that the object will not satisfy the manufacturer's and/or customers' expectations.

2.4.4 Product Cost

2.4.4.1. Manufacturer's Perspective

From the manufacturer's perspective, two costs of importance in the design of a product are *design to cost* (DTC) and *life cycle cost* (LCC).

In the design to cost methodology, the aim is to produce a product such that the unit manufacturing cost does not exceed some specified value. This cost includes the cost of design and development, testing, and manufacturing. DTC is used to achieve the business strategy of a higher market share through increased sales. It is used for most consumer durables and many industrial and commercial products.

In the life cycle cost methodology, the cost under consideration includes the total cost of acquisition, operation and maintenance over the life of the item as well as the cost associated with discarding the item at the end of its useful life. LCC is used for expensive defense and industrial products. Buyers of such products often require a cost analysis from the manufacturer as a part of the acquisition process.

2.4.4.2. Buyer's Perspective

From the buyer's perspective, the costs of importance are the initial acquisition cost, the average operating cost per unit time and life cycle cost. Product performance and cost are closely linked. The value-based notion of quality defined previously deals with this issue.

2.5 Product Reliability

2.5.1 Definition

Reliability of a product conveys the concept of dependability, successful operation or performance, and the absence of failures.

Example 2.6 [Automobile]

A crude way of characterizing the reliability of a product is through the number of problems encountered by customers over some specified time period subsequent to the sale. Consumer organizations carry out such studies and report the results as a guide to readers of consumer magazines. Table 2.3 is a report of one such study. We will discuss more comprehensive characterizations of reliability in later chapters.

Table 2.3. Automobile reliability (problems per 100 vehicles)

Brand	Problems
Toyota	10
Honda	11
Hyundai	11
Subaru	13
Nissan	15
BMW	20
Mazda	20
Volkswagen	20
General Motors	21
Mercedes-Benz	22
Ford Motors	23

■

Since the process of deterioration leading to failure occurs in an uncertain manner, the concept of reliability requires a dynamic and probabilistic framework. We use the following definition:

The *reliability* of a product is the probability that the product (system) will perform its intended function for a specified time period when operating under normal (or stated) environmental conditions.

Reliability theory deals with the interdisciplinary use of probability, statistics and stochastic modeling, combined with engineering insights 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 modeling, (ii) reliability analysis and optimization, (iii) reliability engineering, (iv) reliability science, (v) reliability technology and (vi) reliability management.

Reliability modeling deals with model building to obtain solutions to problems in predicting, estimating and optimizing the survival or performance of an unreliable system, the impact of unreliability, and actions to mitigate this impact.

Reliability analysis can be divided into two broad categories: (i) qualitative and (ii) quantitative. The former is intended to verify the various failure modes and causes that contribute to the unreliability of a product or system. The latter uses real failure data in conjunction with suitable mathematical models to produce quantitative estimates of product or system reliability.

Reliability engineering deals with the design and construction of systems and products, taking into account the unreliability of its parts and components. It also includes testing and programs to improve reliability. Good engineering results in a more reliable end product.

Reliability science is concerned with the properties of materials and the causes for deterioration leading to part and component failures. It also deals with the effect of manufacturing processes (e.g. casting, annealing) on the reliability of the part or component produced.

Reliability management deals with the various management issues in the context of managing the design, manufacture and/or operation of reliable products and systems. Here the emphasis is on the business viewpoint, as unreliability has consequences in cost, time wasted, and, in certain cases, the welfare of an individual or even the security of a nation.

2.5.2 Product Life Cycle Perspective

The reliability of a product over its life cycle varies considerably. A typical scenario is shown in Figure 2.4.[11] A feasibility study is carried out using the specified target value for product reliability. During the design stage, product reliability is assessed in terms of part and component reliabilities. Product reliability increases as the design is improved. However, this improvement has an upper limit. If the target value is below this limit, then the design using available parts and components achieves the desired target value. If not, then a development program to improve the reliability through test-fix-test cycles is necessary. Here the prototype is tested until a failure occurs and the causes of the failure are

[11] Adapted from Court [26].

analyzed. Based on this, design and/or manufacturing changes are introduced to overcome the identified failure causes. This process is continued until the reliability target is achieved.

The reliability of the items produced during the pre-production run is usually below that for the final prototype. This is caused by variations resulting from the manufacturing process. Through proper process and quality control, these variations are identified and reduced or eliminated and the reliability of items produced is increased until it reaches the target value. Once this is achieved, full-scale production commences and the items are released for sale.

The reliability of an item in use deteriorates with age. This deterioration is affected by several factors, including environment, operating conditions and maintenance. The rate of deterioration can be controlled through maintenance efforts, as shown in Figure 2.4.

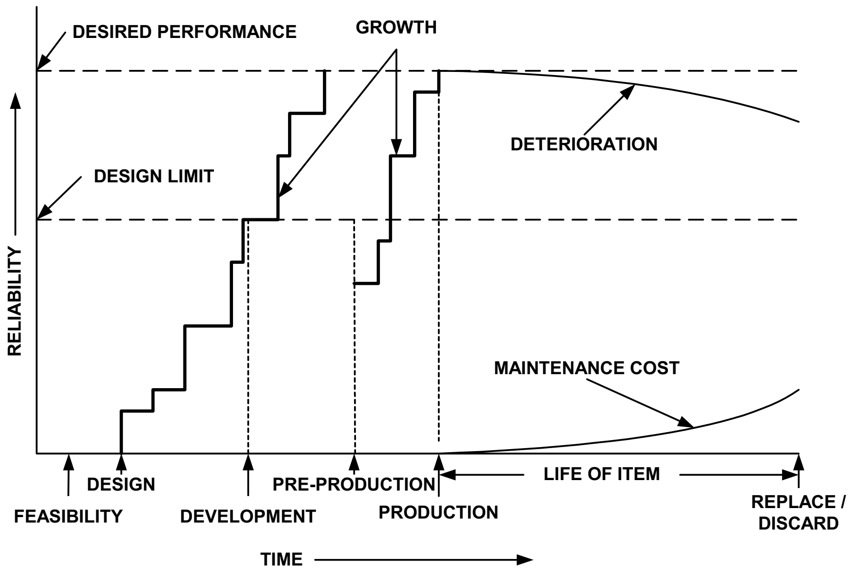

Figure 2.4. Product reliability (product life cycle perspective)

It is worth noting that if the reliability target values are too high, they might not be achievable with development. In this case, the manufacturer must revise the target value and start with a new feasibility study before proceeding further.

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