1 Introduction to Quality by Design

1.1 WHAT IS QUALITY?

"Quality" is one of the most important foundations of trading, whose modern concepts have had a long history since their development in the 1930s. To develop a stable trade relationship, a company must be dedicated to ensure product quality so that their product can be used to (a) "exchange" the money and resources required by the company's operation and growth and (b) create more added value through the accumulation of such resources. A company expects to continually exchange more resources with the market and do more businesses to pursue sustainable operation and growth. In the past decades, many quality scholars and experts have tried to develop better philosophies regarding quality, along with more effective quality assurance (QA) methods to make their society and the world more prosperous and thereby enable human beings to enjoy a better quality of life. Quality, cost, and productivity are the most important factors contributing to the success of a company. Kondo (1995) considered that among the three key management indicators, quality is distinguished from the other two by the following two features:

1. The history of quality (in other words, the relationship between quality and human beings) is far longer than that of either cost or productivity.
2. Quality is the only one of the three indicators to be of common concern to both manufacturer and customer.

Kondo (2000) indicated that quality has a very long history of about 1.7 million years, and he expressed the fact that we feel a deeper connection with it than with either cost or productivity. Hence, improving quality is more easily sympathized with and accepted, and it is harder to refuse than a call to cut cost or to raise productivity. While we may emphasize "quality first" and stress the importance of establishing a "quality culture," for example, we do not commonly use the terms "cost culture" or "productivity culture." Therefore, quality is the center of integrated management (Kondo, 2002). Although

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quality concepts have been developed for a long time, it was not until the 1930s that Dr. Walter A. Shewhart explored quality's significance in modern industry and its control methods with a completely new perspective. After Dr. W. Edwards Deming (a student of Dr. Shewhart) in the 1950s applied the philosophies and methods of quality control to help post-war Japan to win quality leadership in the global market, quality philosophies and various methods spread rapidly worldwide and developed swiftly.

What is quality? "Quality" is a term that can be defined and explained from many different angles. If people have closer definitions about quality, just like the way we define "cars" and "televisions," then quality is concrete and easy to be understood. However, the definition of quality is diverse with various levels and contents, making quality seem abstract, and thus our recognition about it would vary with circumstances. Kano et al. (1984) described that quality bi-dimensional in terms of "objectivity" and "subjectivity," and they pointed out that Aristotle (384–322 BC) first expressed this viewpoint clearly in his book *Metaphysics*. Making the comparison between product A and product B for instance, if product A is evaluated as having a better quality characteristic value than that of product B, then such approach used to evaluate the difference of "quality level" according to defined quality characteristics (or performance indicators) is "objective." If product A and product B are evaluated as "good" or "bad" according to people's different subjectively valued properties (e.g., likes and dislikes, preferences, values), then people recognize quality by using the "subjective" approach. With such concept, we know that the development of the definitions or concepts of quality such as "zero defects," "freedom from deficiencies," and "six sigma" is based on the quality recognition of objectivity, while the definitions or concepts of quality such as "product features," "customer satisfaction," and "customer perception" are based on the quality recognition of subjectivity. The "bi-dimension of quality" provides an effective and easy-to-understand framework to help us know, classify, explain, and analyze the qualities defined and described from various different angles.

Based on the above, when we speak of quality, we can classify it into two types as follows (Taguchi et al., 2000):

1. *Customer-Driven Quality.* What the customer wants—for example, function, appearance, color, and so on. The way we improve customer-driven quality is to fulfill the customer's expressed and latent requirements.
2. *Engineered Quality.* Freedom from what the customer does not want—for example, noise, vibrations, failures, pollution, and so on. The way we improve engineered quality is to lower the variability around an ideal function caused by various sources of variability.

Customer-driven quality is related to market segmentation and product planning; a company determines the business scope through a product's positioning planning and develops the products that can meet the requirements of a customer group within this scope. After marketing and sales personnel identify the market segment and determine product features and portfolios, R&D personnel have to, according to that product planning, develop the products that can be robust against various customer usage conditions so as not to have functional variability in applications. A product has functional variability during customer use, which means that the customer has to bear a certain degree of losses (including invisible loss such as worry and bother as well as visible loss such as time and money). Therefore, the objective of enhancing engineered quality is to reduce societal loss after products are shipped. In the historical development of quality management, customer-driven quality (i.e., planning and development of "functions") is emphasized; but in the twenty-first century, engineered quality (i.e., reduction of functional variability, optimization of "functionality"), which is closely related to lowering functional variability, noise, pollution, and societal loss, plays a very important role in the future development of quality management.

Table 1.1 summarizes the differences between customer-driven quality and engineered quality. Here, we use two well-known definitions of quality to enhance the understanding about the two types of quality: Customer-driven quality means "fitness for use"; engineered quality means "the societal loss a product causes after being shipped." The so-called "fitness for use" by Juran (1992) includes two meanings:

1. *Product Features.* In the eyes of customers, the better the product features, the higher the quality.

TABLE 1.1. Two Types of Quality

Item	Customer-Driven Quality	Engineered Quality
Concept	Features what customer wants (e.g., function per se, features, color and appearance)	Problems customer does not want (e.g., functional variability, defects, failures, noise and vibrations)
Useful definition	Fitness for use (by Dr. Joseph M. Juran)	The loss a product causes to society after being shipped (by Dr. Genichi Taguchi)
Definition component	• Product features • Freedom from deficiencies	• Loss caused by variability of function • Loss caused by harmful side effects
Quality implication	Known or foreseeable items	Unknown or unforeseeable items
Design focus	Function design	Functionality design
Evaluation criteria	Customer satisfaction	Signal-to-noise (SN) ratio
Core method	Quality function deployment	Robust engineering

2. *Freedom from Deficiencies.* In the eyes of customers, the fewer the deficiencies, the better the quality.

As for Taguchi, he considers that a quality problem is concerned with reducing the loss a product causes to society after being shipped. In the context of this definition of quality, loss should be restricted to two categories, other than any losses caused by functions per se:

1. Loss caused by variability of function.
2. Loss caused by harmful side effects.

Therefore, ensuring that a design will perform its intended functions without variability, as well as cause little loss through harmful side effects, is a quality issue. These losses can be viewed as "unknown or unforeseeable items"; that is, the customer's usage conditions are diverse and have various possibilities, so it's very hard to predict product's functional performance and the loss caused by functional variability under various unpredictable or unknown usage conditions. Therefore, in the everyday practice of R&D we usually need verification tests with many samples and ample time to ensure the performance of products. Even so, the central issue of quality by design is to deal with such unpredictable circumstances and make the product's functional performance under various usage conditions achieve the state where the variability is very small. When a product can perform its intended functions without variability, we say that the product has good functionality, and the design methods that make the product achieve functionality are called "functionality design." An indicator called signal-to-noise (SN) ratio is the criteria used to evaluate how well the functionality developed. We will interpret its meaning and applicability in Part II of this book.

Relatively speaking, to achieve customer-driven quality is to deal with "known or foreseeable items" because the clarification of customer requirements or specifications is the task that must be sufficiently done in product planning. If the requirements or specifications cannot be clarified, we can't proceed to the product design stage. Customers use a product to accomplish certain tasks through product functions; hence, at the product planning stage, what the we need to clarify is "what the customer wants" or "what product functions the customer would need to accomplish certain tasks." Customer satisfaction is the criterion used to evaluate how well the function is designed. A design method that is helpful to plan product function and convert that function into the items of technology and product development as well as set quality assurance (QA) points is called quality function deployment (QFD). QFD is an important method to implement function design and quality deployment; and robust engineering (RE) is an effective method to implement functionality design. Both of them are the core focuses of this book. We will introduce QFD and RE, respectively, in Part I and Part II of this book, and we will interpret their integration model and implementation process after that.

1.2 WHY QUALITY BY DESIGN?

The pursuit of quality has emerged as a constant and dominant theme in management thinking since the 1930s. Although the initial theory emerged from American sources, the early industrial applications were predominantly conducted in Japanese companies (Beckford, 1998). At first, Japanese companies used quality control in manufacturing and inspection areas; but in the mid-1950s, quality control spread company-wide, which made quality control a management tool. Total quality management (TQM) is the tool formed by integrating all the concepts, facilitation programs, and techniques of quality management for implementing company-wide quality management.

The ultimate objective of TQM is customer satisfaction. Companies must, at the appropriate time and price, provide products with the quality that satisfies customers, thereby exchanging the needed resources for subsistence and operation. Through accumulated resources, companies create more added values and obtain more resources, so as to pursue sustainable development and growth. If a company is viewed as a collection of various planning and operational activities, all these activities can be represented using a value chain (Porter, 1985). As quality management is extended to the whole company, assurance activities of quality push toward the upper reaches of the value chain. In other words, during technology development and new product development (NPD), quality must be "built in" and "designed in." This is because the quality built on these stages has the maximum return and benefit in cost reduction and customer satisfaction. It far surpasses the improvement effects brought about, after design release, by relying on promotion efforts in selling or detection and modification in manufacturing.

1.3 HOW TO DESIGN FOR QUALITY

As mentioned above, we classify quality into two types: customer-driven quality and engineered quality. Therefore, the design methodologies needed to realize the quality of the two types are also different.

In late 1960s, when Japanese products started the period from "designed by imitation" to "developed by originality," the so-called "customer-driven quality" becomes important; that quality is the quality built into the product according to the voice of the customer (VOC). Also, customer-driven quality can be further described based on the definition of quality, "fitness for use," defined by Juran (1992). The "fitness for use" defined by Juran includes both meanings of "product features" and "freedom from deficiencies"; that is, it expresses that customer satisfaction is determined by how the product achieves the balance between more features and fewer deficiencies, and that balance state is quality. To achieve customer-driven quality and improve customer satisfaction, a quality assurance (QA) method called quality function deployment (QFD) applied to NPD was developed; it can effectively convert

VOC into quality characteristics as well as their design targets, as well as deploy various subsystems, components, parts, and process elements and facilitate the interrelationships needed to achieve those targets. The so-called quality function deployment (broadly defined) is actually the short form of both "quality deployment" and "quality function deployment (narrowly defined)"; the former is the method used to ensure product quality, and the latter is used to ensure work quality and process quality ("quality function" means the job functions that create quality). QFD is considered as a comprehensive approach to function design and quality deployment. It simultaneously focuses on function design as well as how to systematically deploy the designed function and the quality we want to assure into the whole NPD process and realize them.

On the other hand, to achieve engineered quality and reduce various losses brought by functional variability, a QA method called robust engineering (RE) (also known as quality engineering) applied to technology development and NPD was developed; it is a methodology of functionality evaluation and design which can make the functionality of technology and product approach its ideal state as much as possible and further avoid various quality problems arisen at the downstream. In other words, RE is to optimize functionality.

In Section 1.4, we interpret the relationship between QFD and NPD in detail, and we describe QFD's importance and evolutionary strategy based on the reflections on "the development of QFD" and "the evolution of NPD philosophy." In Section 1.5, we interpret the importance of technology development and its relationship with RE strategy.

1.4 NEW PRODUCT DEVELOPMENT AND QFD

Nowadays, NPD's quality management relies upon the guidance of modern NPD philosophy and integrated application of quality tools and methodologies to deal with the following three major issues:

1. *Improving R&D Productivity.* Today's competition on the market is time-based competition. Products require variety and shorter time from development to market, yet their lifetime after being launched to the market is relatively short. Consequently, R&D productivity needs to be enhanced so as to deal with competition. R&D productivity is defined as the R&D capability that can (1) more easily meet market demands for product variety and higher quality levels, (2) more readily combine company's existing "technology seeds" with "customer needs" or further create new customer requirements, (3) more easily prevent potential quality problems through early prediction, (4) effectively more accumulate product-development knowledge in a systemic manner and effectively transfer to future generations, and (5) attain more leverage from critical resources and thereby reduce product development costs.

2. *Managing NPD Cycle in Supply Chain Environment.* The design of supply chain has given rise to a situation in which product development, manufacturing, and support activities are spread out over different areas and companies. Therefore, modern NPD philosophy has shifted from concurrent engineering (CE), emphasizing paralleling of activities, to integrated product and process development (IPPD), stressing the integration of product design activities and process design activities. The latter more unequivocally reflect major challenges of NPD management in today's supply chain environment.
3. *Creating Attractive Quality.* Attractive quality is defined as an unexpected new quality achieved by meeting customers' latent requirements and is synonymously used with customer delight (Kano, 2002). Kano (2002) observed that compared with competitors in the same target market, most product makers, in particular of mature products, usually have considerably similar capabilities in surveying the "voice of the customer" and converting customer expressed requirements into concrete product specifications to conduct development, and that therefore creating product differentiation and the customer's surprised response is not easy. Since 1984 Kano has been advocating the concept and process of attractive quality creation (AQC) in order to serve as a quality strategy for NPD to realize customer delight (Kano et al., 1984). Garvin (1987), who held a similar viewpoint, also considered that in order to achieve quality gains, managers need a new way of thinking, a conceptual bridge to the customer's vantage point.

The term *quality function deployment* (QFD) refers to a concept and methodology of NPD under the umbrella of TQM. QFD was conceived in Japan in the late 1960s, and Akao first presented the concept and method of QFD (Akao and Mazur, 2003). QFD is one of the few techniques that could potentially have a quality improvement impact throughout a company's product development process (Booker, 2003). Its objectives are to identify the customer, determine what the customer wants, and provide a way to meet the customer's desires (Maddux et al., 1991). QFD combines various design engineering and managerial tools to create a customer-driven approach to developing new products (Özgener, 2003). It is the most complete and convincing methodology that can identify and prioritize customer requirements and translate these requirements into appropriate company requirements at each stage of the product life cycle (Conti, 1989; Burke et al., 2002).

We, in view of the importance of having to consider the foregoing three major issues of NPD quality management, make reflections upon the development of QFD and the evolution of NPD philosophy (as described in Sections 1.4.1 and 1.4.2) to help us identify some key issues and further develop QFD's expanded system (as described in Chapter 3) for more effective NPD.

1.4.1 Reflections on the Development of QFD

QFD has been developed for 35 years, and the published literature on QFD reveals that it has achieved a state where it is well known in the academic literature of product development management and has been widely applied in many countries (Cheng, 2003). Although QFD has attracted great attention and its importance has been recognized, its popularity has not always translated into successful practice (Akao, 1988). The reflections on the development of QFD are described as follows:

1. *Recognition of QFD definitions, QFD concepts, and QFD's relationships with NPD needs to be reinforced.* After QFD was internationally spread and transferred, some misunderstandings about the essence of QFD were gradually engendered and can be found in various relevant articles and books. The common misunderstandings include: (1) quality deployment being equivalent to quality chart and (2) QFD being equivalent to quality deployment. And the result is an incomplete and ineffective QFD in practice.

These misperceptions have been noticed by some researchers (Fortuna, 1988; Cox, 1992; Cohen, 1995; Partovi, 1999; Bouchereau and Rowlands, 2000; Cristiano et al., 2000, 2001; Akao and Mazur, 2003; Booker, 2003; Akao, 2004). Akao (2004) has undertaken to reinforce QFD concepts and contents regarding the second-most common misconceptions about QFD. Aside from that, views held by other researchers are mostly no more than descriptions of phenomena observed with no concrete response to those issues. In addition, the main shortcomings most often pointed out (Zairi and Youssef, 1995; Prasad, 1998; Bouchereau and Rowlands, 2000) are also caused by misconceptions about basic concepts of QFD and its relationships with NPD.

2. *The universal QFD implementation roadmap which includes the matrix-making of QFD and the main activities of NPD, as well as the essential tool set used in that roadmap, need to be developed.* The most frequently seen form of QFD is presented by four major matrixes and the relationships between them (Sullivan, 1986; Hauser and Clausing, 1988; Prasad, 1998; Kathawala and Motwani, 1994; Cohen, 1995). The main activity in most current implementations of QFD is the generation of these four charts (Prasad, 1998). However, if we regard QFD as the QA system managing NPD, then the generic roadmap of QFD needs to include the matrix-making of QFD and the main activities of NPD so that it can perform a higher value of QFD toward NPD's QA management.

Furthermore, if we regard QFD as a framework that can integrates various design tools, it is worthwhile to explore which tools can be systematically organized as the essential tool set used in NPD and QFD.

3. *QFD's research and development in Japan and the West need to be fused.* It can be analyzed that there is a main difference between the development trends of QFD in Japan and the West over the past 35 years: the former's QFD, in concept and methodology, toward the direction of "how to add value to every work activity in NPD cycle to achieve quality assurance and

competitively improve product quality" (Mizuno and Akao, 1978; Kogure and Akao, 1983; Akao, 1990a, b; Akao, 1997; Shindo, 1998; Akao, 2001a, b; Akao and Mazur, 2003; Cheng, 2003; Akao, 2004), in contrast to the latter's QFD toward the direction of "how to integrate various design tools and methodologies as well as more powerful numerical analysis methods to achieve QA and competitively improve product quality" (Clausing, 1988; Ross, 1988; Clausing and Simpson, 1990; Clausing and Pugh, 1991; Bendell et al., 1993; Clausing, 1993; Masud and Dean, 1993; Wasserman et al., 1993; Armacost et al., 1994; Lu et al., 1994; Eureka and Ryan, 1995; Khoo and Ho, 1996; Zhang et al., 1996; Terninko, 1997; ReVelle et al., 1998; Zhou, 1998; Dawson and Askin, 1999; Temponi et al., 1999; Bouchereau and Rowlands, 2000; Kim et al., 2000; Creveling et al., 2002; Büyüközkan et al., 2004a, b; Ramasamy and Selladurai, 2004; Chen et al., 2005; Lai et al., 2005; Yan et al., 2005).

Though QFD originated in Japan, currently most literatures published in English lay particular stress on the latter mentioned above. This has made the international mainstream of QFD's research and development overlook integration with many researches and practices published in Japanese.

4. *Reinforcement of QFD's effectiveness needs a renewal in both its structure and contents.* Since 1994, Akao has advocated "development management" to facilitate the further advancement of QFD, and he also indicated that another important research topic should be a management technology for making QFD more effective inside an organization (Akao, 1997). The direction of QFD development advocated by Akao can be concretely viewed as how, in harmony with the dominant NPD philosophy, to develop a more process-oriented approach to implement QFD, in order to effectively support the corporate NPD cycle.

Nevertheless, most QFD research has focused on three areas that are less related to the achievement of this evolution objective. The three focused areas are: (1) scoring mechanics of the matrix of matrices model (Masud and Dean, 1993; Wasserman, 1993; Wasserman et al., 1993; Armacost et al., 1994; Lu et al., 1994; Khoo and Ho, 1996; Zhang et al., 1996; Franceschini and Rossetto, 1997; Moskowitz and Kim, 1997; Park and Kim, 1998; Zhou, 1998; Dawson and Askin, 1999; Temponi et al., 1999; Bouchereau and Rowlands, 2000; Kim et al., 2000; Franceschini, 2002; Shin et al., 2002; Büyüközkan et al., 2004a, b; Ramasamy and Selladurai, 2004; Chen et al., 2005; Lai et al., 2005); (2) case studies of different industrial product applications (Cohen, 1988; Hauser, 1993; Armacost et al., 1994; Ghobadian and Terry, 1995; Mrad, 1997); and (3) management applications—such as strategic planning, policy deployment, project selection, and so on (Sullivan, 1988; Lu et al., 1994; Crowe and Cheng, 1996; Partovi, 1999; Creveling et al., 2002; Hunt and Xavier, 2003; Killen et al., 2005; LePrevost and Mazur, 2005). There has been a lack of interest in a comprehensive renewal of QFD structure and contents.

5. *QFD needs to be adapted for use in today's supply chain environment.* The application of QFD to product development according to the business model of a company is achieved as follows: (1) in companies that emphasize own

product design and (2) in companies that emphasize fabrication engineering. The difference in business models derives from the division of labor in global supply chain.

Indeed, QFD was conceived when Japanese industries were advancing toward product development based on originality, and it was therefore not designed for application in a business model that emphasizes fabrication engineering. The difference between the two corporate NPD models causes QFD to vary in its application focus (Cheng, 2003), so that QFD can be practiced more effectively in a supply chain environment. However, as of yet there is no QFD reinforced for the NPD model of fabrication suppliers.

6. *The mathematics underlying the other deployments beyond the "quality chart" needs to be specified.* Much of the QFD research focuses too much on the mechanics of scoring, while their range is restricted to a quality chart only (Masud and Dean, 1993; Wasserman, 1993; Khoo and Ho, 1996; Zhang et al., 1996; Franceschini and Rossetto, 1997; Moskowitz and Kim, 1997; Park and Kim, 1998; Zhou, 1998; Dawson and Askin, 1999; Temponi et al., 1999; Franceschini, 2002; Shin et al., 2002; Büyüközkan et al., 2004a, b; Ramasamy and Selladurai, 2004; Chen et al., 2005; Lai et al., 2005). QFD is not a method for finding an optimal design algorithmically, but specifying the mathematics underlying the overall QFD cycle (including the deployments of subsystems, process, technology, cost, and reliability beyond the quality chart) can facilitate understanding of QFD process and thereby yield greater benefits from its application.

1.4.2 Reflections on the Evolution of NPD Philosophy

Evolution in NPD philosophy signifies the needs for a change in NPD operating patterns and for a new development in core methodology. The reflections on NPD philosophy are described as follows:

1. *Changes in emphasis in the evolution of NPD philosophy oblige the enhancement of the application depth of existing methodologies and their integration with other tools and methodologies.* The NPD philosophy of CE has changed the operating pattern of NPD from over-the-wall or sequential engineering to parallel processing or simultaneous engineering. It mainly emphasizes interdepartmental communications in the NPD cycle. Later, the new philosophy of IPPD, considered an extension of CE (Allen, 1990; Prasad, 1996; Magrab, 1997; Usher et al., 1998), further concretely described and emphasized the essence of CE on product and process design integration.

Although in terms of basic concepts the two philosophies do not differ significantly (Allen, 1990; Turino, 1992; Clausing, 1993; Parsaei and Sullivan, 1993; Syan and Menon, 1994; Prasad, 1996; Zhang et al., 1996; Magrab, 1997; Wang, 1997; Franceschini, 2002), their change in emphasis (i.e., from emphasizing interdepartmental communications to product and process design integration) signifies the need to enhance the application depth and integration of existing core methodologies (e.g., QFD, computer-aided design, computer-aided manufacturing, design for manufacturing and assembly, rapid prototyping, etc.) (Allen, 1990; Turino, 1992; Kusiak, 1993; Parsaei and Sullivan, 1993; Syan and Menon, 1994; Prasad, 1996; Wang, 1997; Franceschini, 2002). Take the application of QFD in CE as an example. Even if only the first form of QFD—quality chart (also known as the house of quality)—is used, interdepartmental communications can be effectively improved (Sullivan, 1986; Hauser and Clausing, 1988; Akao and Mazur, 2003) and thus the weaknesses of the over-the-wall approach can be significantly improved. Therefore, using the quality chart alone has become the most common method of QFD application in CE. However, in applying QFD in IPPD, the deployments of subsystems, components, parts, process, and their relationships beyond the quality chart must be further implemented, and their integration with other design tools and methodologies must be stressed to enable product and process design integration.

2. *Core methodologies must tie in with philosophical evolution to have new development.* Since 1994, Akao has advocated development management to urge proper recognition and further advancement of QFD (Akao, 1997). Nevertheless, though the new philosophy of IPPD, considered an extension of CE, places more emphasis on the use of a systematic way to conduct integrated product and process development, the main method used, QFD (Ross, 1988; Shina, 1991; Carter and Baker, 1992; Wheelwright and Clark, 1992; Clausing, 1993; Kusiak, 1993; Parsaei and Sullivan, 1993; ReVelle et al., 1998; Shina, 1994; Syan and Menon, 1994; Prasad, 1996; Magrab, 1997; Schmidt, 1997; Monplaisir and Singh, 2002; Wang, 1997; Usher et al., 1998; Franceschini, 2002), has not touched on how itself can be renewed to adapt to the differences in applications resulting from changes in the dominant NPD philosophy. This situation indicates that in dealing with the key issues of NPD, the structural integrity of QFD is considered capable of achieving different NPD philosophies. However, the evolutionary needs of QFD have been neglected. This is why QFD research has focused far more on case studies than on comprehensive renewal of QFD structure and contents.

3. *New design tools and methodologies need a common framework that can achieve integration with existing methodologies.* One NPD philosophy can predominantly affect the operating pattern of an NPD cycle. However, an NPD cycle cannot achieve good development management by relying on just one tool or methodology. Numerous and complex items are processed by NPD, including product planning, concept development, product design, process design, production planning, and management of quality, technology, cost, and reliability. As a result, design tools and methodologies generally apply, depending on the timing and range of NPD. Hence, to continue improving development management, in addition to adopting better new tools and methodologies, a common framework is required to integrate new and existing tools of NPD to create a synergistic whole. QFD can play a dual role, as both a design methodology and a framework integrating various design methodologies.

1.5 TECHNOLOGY DEVELOPMENT AND FUNCTIONALITY DESIGN

Since Prahalad and Hamel proposed the concept of *core competence* in 1990, top management has to recognize the concept of *corporation* as a portfolio of competencies and, based on the strategy of developing core competence, build a competitive advantage by going beyond the short-term standpoint of focusing on products. Prahalad and Hamel (1990) stated that "the corporation, like a tree, grows from its roots. Core products are nourished by competencies and engender business units, whose fruit are end products." Therefore, it's not hard for us to know that technology development capability is one of the most important factors to develop and keep reinforcing core competence, that is, the key to establish competitive advantage.

Simply speaking, technology development capability signifies the capability of developing the technology with high readiness before product planning and ensuring that the technology can be effectively applied to develop the products with high quality, low cost, and short time to market. For different design targets of different products, the technology must also have a speedy adaptability which can effectively fulfill them. Enhancing technology development capability is helpful for a company to gain the following benefits:

1. Reinforcing core competence to establish and keep developing the company's competitiveness.
2. Establishing technology intelligence capital to define an industry's technology framework and standards or constitute the technology development barrier adverse to the competitors.
3. Gaining technology leadership to escape from the price war.
4. Applying technology to develop core products, as well as seeking new business concepts based on them.

When we speak of quality in two different fields such as technology development and NPD, the word "quality" would signify different meanings. At the technology development stage, since the planning for technology application and product concept may not be conducted yet, technology development is defined as researching a technical system formed by energy transformation. The quality of that technology means that energy transformation has achieved its ideal state (we call the ideal state an "ideal function"). Therefore, while we develop a technology that can make the energy fully transform in accordance with its ideal function (without energy loss or variability), we may say that technology is high quality, that is, its functionality or functional robustness is good. On the contrary, if energy transformation varies around the ideal function, that technology would create problems in applications and cause some loss: The larger the variability, the worse the quality the technology development and the worse the applicability. The so-called technology development is defined as follows: By means of small scale experiments, test pieces and simulations to predict and develop good functionality. Most work of technology development is to resist the functional variability caused by various sources of variability, so R&D (research & development) work can be regarded as robustness development (RD) of technologies or products.

Ideal function is energy-related and an energy transformation; through that energy transformation, a certain function can be provided. However, in the real world there are various sources of variability which cause the loss of that energy transformation and thus the function cannot fully take effect and be performed. According to conservation of energy, the lost energy will be used to create an unintended function and then produce various defect phenomena. During technology development, the way to improve various defect phenomena of quality characteristics is "firefighting"; the way to study how to make energy transformation not affected by various sources of variability to fully perform its ideal function and further to avoid causing various defect phenomena of quality characteristics is "proactive prevention." The latter way is the optimization of technology. The so-called technology optimization in this book is *optimized design of functionality*, and the design method to optimize functionality can be regarded as *technology development strategy* itself which can be broadly applied to various technological fields. RE plays the strategic role of realizing that optimization. It focuses on the rationalization and efficiency of technology development (including a totally new technological area), so as to make R&D personnel, at the possible lowest cost, predict and early improve the functional performance of a technology under various sources of variability. Once the functional performance is in a robust state, the technology realizes high quality. We will introduce this method and its implementation process in Part II of this book.

1.6 OUTLINE OF THIS BOOK

This book's body of framework is divided into two parts: Optimizing design for function and optimizing design for functionality. The content of each chapter is introduced as follows:

1. Chapter 1 describes the concept of quality and how to design for quality.
2. Chapter 2 introduces the methodology, QFD, used to optimize design for function and the dominant approaches to it.
3. Based on Chapter 2, Chapter 3 develops an expanded system of QFD and its implementation process using the NPD approach.
4. Chapter 4 describes the common seen R&D paradigm in practice and its improvement opportunities.
5. Chapter 5 presents how to evaluate a technology and conduct comparative assessment of technologies.
6. Chapter 6 describes the methodology, robust engineering (RE), used to optimize design for functionality, and it presents case studies of robust technology development.

7. Chapter 7 describes the technical and managerial key success factors (KSFs) for managing R&D paradigm shift.
8. Chapter 8 develops an integration strategy for QFD, RE, and other breakthrough strategies, such as DFX (design for excellence), DFSS (design for Six Sigma), and BOS (blue ocean strategy), in order to realize the customer-focused, rationalized, and efficient R&D.

The linkage structure of each chapter of this book is shown in Figure 1.1.

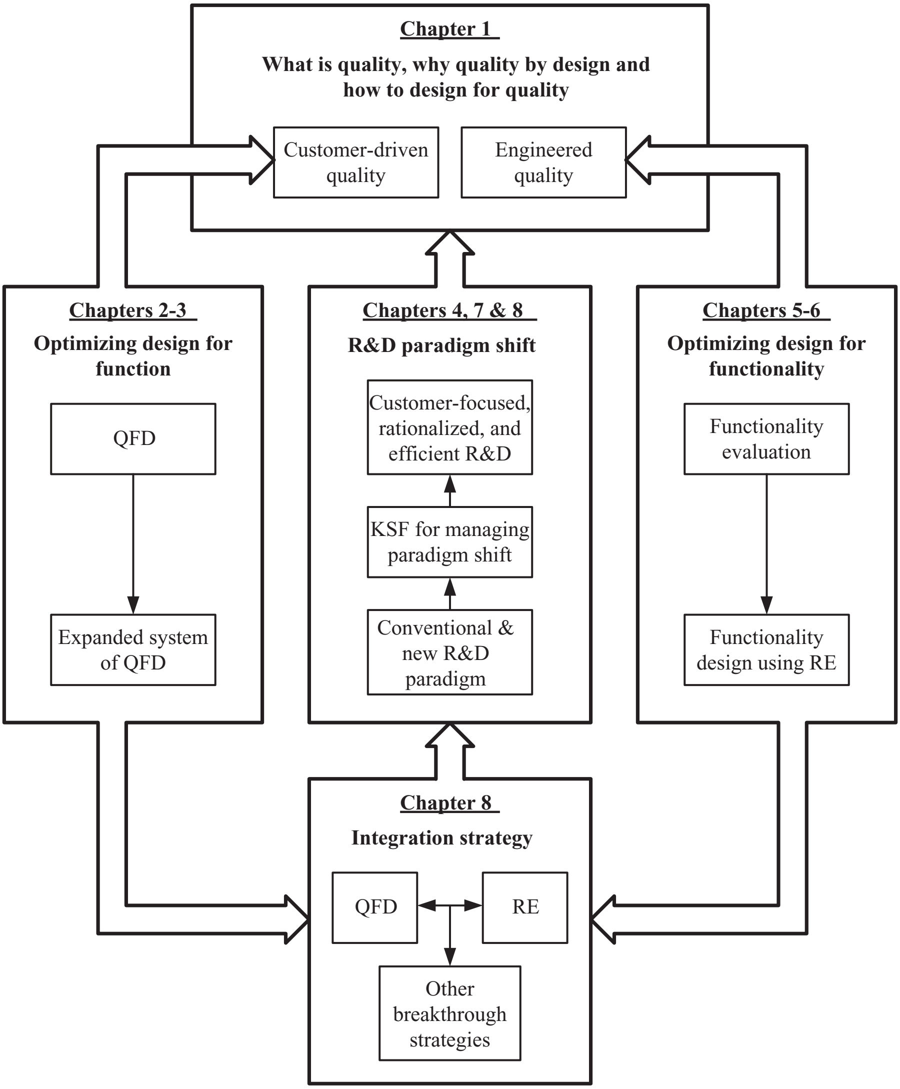

Figure 1.1. Framework of this book.