Invited Review

Quality function deployment: A literature review

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Received 2 May 2001; accepted 18 January 2002

Abstract

This paper presents a literature review of quality function deployment (QFD) based on a reference bank of about 650 QFD publications established through searching various sources. The origination and historical development of QFD, especially in Japan and the US, are briefly accounted first, followed by a partial list of QFD organizations, softwares, and online resources. Then a categorical analysis is conducted about QFD's functional fields, applied industries and methodological development. Ten informative QFD publications are also suggested, particularly for those who are not yet familiar with QFD. It is hoped that the paper can serve the needs of researchers and practitioners for easy references of QFD studies and applications, and hence promote QFD's future development.
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Keywords: Quality management; Product development; Customer needs; Quality function deployment (QFD)

1. Introduction

Quality function deployment (QFD) is "an over-all concept that provides a means of translating customer requirements into the appropriate technical requirements for each stage of product development and production (i.e., marketing strategies, planning, product design and engineering, prototype evaluation, production process development, production, sales)" (Sullivan, 1986b). Since its initial development in Japan in the late 1960s and early 1970s, especially since its rapidly spreading to the US in the 1980s and later to many industries in many nations, a vast literature on QFD has evolved. To suit the different needs of QFD researchers and practitioners, its literature needs categorizing and reviewing. This is a meaningful but difficult work that seems having not been done yet.

For that purpose, we have established a reference bank with about 650 QFD publications through searching various sources, which are listed alphabetically at the end of this paper. But it should be noticed that only a few papers in the transactions of the annual US QFD Symposium since 1989 and of the annual International QFD Symposium since 1995 are included and the readers are referred to the websites of the US QFD Institute (http://www.qfdi.org/transact.htm) and the International Council for QFD (http://www.icqfd.org/transact.htm) for a full list of such papers. Although our literature search is admittedly incomplete, we believe that it covers a reasonable

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portion of QFD publications and thus is a useful source for QFD researchers and practitioners. We welcome input from readers on additional publications to enrich the QFD reference bank.

In this paper, we try to conduct a literature review of QFD based on the above-mentioned reference bank. We first give a brief historical review of QFD with emphases on its origination and its development in Japan and the US. A number of QFD organizations, softwares, and online resources are also listed for references. Then we present a categorical analysis of QFD applications in terms of why and where it has been applied (i.e., for what purposes and to which industries QFD has been applied). We then proceed to review the methodological development of QFD, including quantitative methods applicable to it and its extensions and implementation issues. A list of 10 informative and popular QFD publications is also given, especially for the easy references of readers who are not yet familiar with QFD. It is hoped that this paper can serve the needs of interested readers for references of QFD studies and applications, and hence promote the future development of QFD.

Not included in this paper but available from the authors, the QFD references are grouped according to their contents into four broad categories: general introduction, functional field, application industry, and theoretical development, and each category is further divided into sub-categories to classify the references more specifically, so that readers can easily find relevant references on specific topics. Moreover, the QFD references are also classified according to publication type (i.e., books, theses, technical reports, journal papers, and so on) and the distribution of the journal papers is also given according to where they were published, so that readers can conveniently choose a specific type of publications or a specific journal to look for relevant topics.

2. A brief review of QFDs history

2.1. Origination of QFD

In the Foreword for J. Terninko's book *Step by Step QFD* (Terninko, 1997), B. King wrote,

"In the 1960s, Quality Control and Quality Improvement had a distinctively manufacturing flavor in Japan. ... in the late 1960s and early 1970s, Joji [Yoji] Akao and others went to work on improving the design process so that when the new product was introduced to manufacturing, it was high quality from the beginning. The process for improving design was called Quality Function Deployment (QFD). From 1975 to 1995, this tool/process was integrated with other improvement tools to generate a mosaic of opportunities for product developers."

In Chapter 21, Quality Function Deployment, of the second edition of *Gower Handbook of Quality Management* edited by D. Lock, Hill (1994) wrote similarly,

"QFD evolved from a number of different initiatives between 1967 and 1972, but the two main drivers which led to its creation in Japan were those:
1. To improve the 'quality of design'.
2. To provide manufacturing and field staff with the planned quality control chart (showing the points to be controlled within the production process) *before* the initial production run."

Therefore, it is clear that "it was the struggle by product designers under the total quality control movement to improve their work that spawned quality function deployment in Japan" (Neff, 1991).

2.2. Development of QFD in Japan

Historically, Japanese industry began to formalize the QFD concepts when Mr. Oshiumi of the Kurume Mant plant of Bridgestone Tire produced a processing assurance chart containing some of QFD's main characteristics in 1966 and K. Ishihara developed the ideas of "functional deployment of business" similar to those of QFD and applied them to Matsushita in the late 1960s (Cohen, 1995; Hill, 1994; Marsh et al., 1991). However, it was Akao who first realized the value

of this approach in 1969 and wanted to utilize its power during the product design stage so that the product design characteristics could be converted into precise quality control points in the manufacturing quality control chart (Hill, 1994). After several industrial trials, Akao wrote a paper on this new approach in 1972 and called it *hinshitsu tenkai* (quality deployment). This paper and Nishimura (1972) were the first two papers fostering the then new concept of QFD known to the West.

In the meantime, the Kobe Dockyard of Mitsubishi Heavy Industries began to apply the ideas of QFD in 1971 following Akao's suggestion (Pardee, 1996), and Nishimura at Kobe produced a quality table that showed the correlation between the customer-required quality functions and the counterpart engineering characteristics between 1972 and 1974 (Hill, 1994; Nishimura, 1972). Akao formulated all these into a procedure channelling the customer requirements from the design stages down to the production operations, which was called *hinshitsu kino tenkai* (quality function deployment) (Cohen, 1995; Hauser and Clausing, 1988; Hill, 1994; Marsh et al., 1991; Prasad, 1998a; Sullivan, 1986b). QFD was introduced to Toyota's Hino Motor in 1975 and Toyota Autobody in 1977 with impressive results, and was later introduced into the whole Toyota group.

A Japanese book on QFD edited by Mizuno and Akao, *Deployment of the Quality Function*, was published in 1978, showing the fast development and wide applications of QFD in Japan. Two years later, Kayaba won the Deming Prize with special recognition for applying QFD to bottleneck engineering (Cohen, 1995; Marsh et al., 1991).

Through the above-described explorations and practices, QFD has been successfully used in many Japanese industries, such as agriculture systems, construction equipment, consumer electronics, home appliances, integrated circuits, software systems, steel, synthetic rubber, and textile (Akao, 1990a; Hauser and Clausing, 1988; Kim and Moskowitz, 1997).

2.3. Development of QFD in the US

After more than 10 years development of QFD in Japan, Kogure and Akao published "Quality function deployment and CQWC in Japan" in the October 1983 issue of *Quality Progress*, which may mark the entrance of QFD into the US. B. King, the founder and executive director of GOAL/QPC (Growth Opportunity Alliance of Lawrence/ Quality Productivity Center: http://www.goalqpc. com) and D. Clausing of Xerox and later MIT were the first two to learn of QFD, and L. Sullivan of Ford Motor and the founder of American Supplier Institute (ASI: http://www.amsup.com) was also one of the first to grasp the importance of the QFD concept in the US (Cohen, 1995). King then published the first full-length QFD book in the US: *Better Designs in Half the Time* (GOAL/ QPC, 1987). Clausing unified QFD with Taguchi's method, Stuart Pugh's concept selection process and other approaches into a system for product development called *Total Quality Development* (ASME Press, 1994), and Sullivan wrote an early and influential QFD paper entitled "Quality function deployment" in the June 1986 issue of *Quality Progress*. Co-authored with J. Hauser, Clausing's expository and inspiring article "The house of quality" in the May–June 1988 issue of *Harvard Business Review* was also well-known and "probably increased QFD's popularity in the United States more than any other single publication or event" (Cohen, 1995).

From an organizational point of view, ASI and GOAL/QPC have done a great job in publicizing QFD in the US (Prasad, 1998a). Especially, they have jointly sponsored the annual QFD Symposium held in Novi, Michigan since 1989, and the transactions of these symposia have become the important publications on QFD. In 1993, a more specialized institute, the QFD Institute (QFDI: http://www.qfdi.org), was founded as a non-profit, research and educational organization for the advanced study of QFD. Since then, the US QFD Symposium (http://www.qfdi.org/transact.htm) has been organized by this Institute.

The first recorded case study in QFD in the US was probably in 1986 when Kelsey Hayes used QFD to develop a coolant sensor, which fulfilled critical customer needs such as "easy-to-add coolant", "easy-to-identify unit", and "provide cap removal instructions" (King, 1987a; Prasad, 1998a). Early adopters of QFD in the US included

3M Company, AT&T, Baxter Healthcare, Budd, Chrysler, DEC, Ford Motor, General Motors, Goodyear, Hewlett-Packard, IBM, ITT, Kodak Eastman, Motorola, NASA, NCR, Polaroid, Procter and Gamble, and Xerox (Adiano and Roth, 1994; Bosserman, 1992; Cohen, 1995; Dika, 1995; Griffin, 1992; Hauser and Clausing, 1988; Hill, 1994; Kim and Moskowitz, 1997; Morrell, 1987; Prasad, 1998a; Schaal and Slabey, 1991; Sharkey, 1991; Shipley, 1992). Many other companies have used QFD and realized significant benefits, and the tool continues to grow in popularity. Griffin and Hauser (1992) believe that there are more than 100 major companies using QFD in the US. To find more company names, the readers are referred to the annual US QFD Symposium transactions (http://www.qfdi.org/transact.htm).

2.4. Development of QFD in other regions

QFD's influence also goes beyond Japan and the US. For example, there are reported QFD applications and studies in countries/regions such as *Australia* (Anonymous, 1995b; Barnett, 1991), *Belgium* (Moenaert and Caeldries, 1996; Selen and Schepers, 2001), *Brazil* (Matsuda et al., 1998; Radharamanan and Godoy, 1996), *Danmark* (Holmen and Kristensen, 1998), *Finland* (Rajala and Savolainen, 1996), *Germany* (Herrmann et al., 2000; Pfohl and Ester, 1999), *Hong Kong* (Chan, 2000; Chin et al., 2001; Ho, 2000; Ko and Lee, 2000; Lam and Zhao, 1998; Leung, 1997; Tse, 1999), *India* (Maduri, 1992; Singh and Deshmukh, 1999), *Ireland* (Hallberg et al., 1999a), *Israel* (Glushkovsky et al., 1995), *Italy* (Ghobadian and Terry, 1995), *Korea* (Han et al., 1998; Kim et al., 2000c), *Malaysia* (Anonymous, 1998), *Netherlands* (Govers, 1996, 2001), *Scotland* (Curry and Herbert, 1998), *Singapore* (Hwarng and Teo, 2001; Lim and Tang, 2000; Lim et al., 1999), *Slovenia* (Starbek et al., 2000), *Sweden* (Anonymous, 1994a; Fuxin et al., 2001; Sandelands, 1994a; Tottie and Lager, 1995), *Taiwan* (Lyu and Gunasekaran, 1993; Philips et al., 1994), *Turkey* (Koksal and Egitman, 1998), *UK* (Curry, 1999; Barnes and Vidgen, 2001; Booth, 1995; Lowe and Ridgway, 2000a; Martins and Elaine, 2001; Parr, 1995; Poolton and Barclay, 1996; Taylor, 1997; Veness

et al., 1996; Zairi and Youssef, 1995), and *Europe* (Barad and Gien, 2001; Miller et al., 1992). See also Bouchereau and Rowlands (2000b) and Mazur (1994) for reviews of QFD practice around the world.

Since 1995, the annual International Symposium on QFD has been held in US or other countries (http://www.icqfd.org/transact.htm). At the end of the 3rd International Symposium on QFD in 1997, the International Council for QFD (ICQFD: http://www.icqfd.org) was established as a non-profit organization chaired by Professor Akao and incorporated in Michigan, US. The Council includes representatives from the Union of Japanese Scientists and Engineers (http://www.juse.or.jp), US QFD Institute, Linköping University (Sweden: http://box.ikp.liu.se/publications/gemensamma/qfdprogm.html), MacQuarie University (Australia), NTQI, FCO, UFMG (Brazil), and QFD Institut Deutschland (Germany: http://www.qfd-id.de), which are all active QFD organizations around the world and show the globalization of the QFD technique.

For more about QFD's historical development, the readers are referred to Akao (1990b, 1997), Cohen (1995), Kochhar and Akao (1983), Hill (1994), Neff (1991), Kim and Moskowitz (1997), and Prasad (1998a).

2.5. QFD resources

QFD's popularity can also be witnessed by the great amount of QFD resources available. First, there are many organizations which provide consulting and/or training in QFD, such as: Applied Marketing Science (US: http://www.ams-inc.com), ASI Quality Systems Ltd. (UK: http://www.asiqs.co.uk), Becker and Associates (US: http://www.becker-associates.com), C2C Solutions (US: http://www.c2c-solutions.com), CSP International (France: http://www.csp.fr), DRM Associates (US: http://www.npd-solutions.com), INFOnetics (US:http://www.infonetics.net), Innovation Process Management (UK: http://www.ipm-marketing.co.uk), INSYTEC B.V. (The Netherlands: http://www.insytec.com), J.H.Berk and Associates (US: http://www.jhberkandassociates.com), Learn Firm.com (US: http://www.learnfirm.com), PQM

(Czech: http://www.pqm.cz), ProAction Development (US: http://www.proactdev.com), Quality Associates International (US: http://www.quality-one.com), Quality Improvement International (US: http://www.qualityi2.com), and Vicente Luz Consultores Associados Ltda. (Brasil:http://www.vluz.com.br).

Second, a number of QFD softwares have been developed to facilitate the QFD process, including QFD for Software Evaluation (by Fawsy Bendeck of Universität Kaiserslautern, Germany: http://www.agr.informatik.uni-kl.de/~bendeck/qfd/index.html), QFD Designer (by Qualisoft/Fulfillment Services, USA: http://www.qualisoft.com), QFD Scope (by Integrated Quality Dynamics, US: http://www.iqd.com), QFD/CAPTURE (by International TechneGroup, US: http://qfdcapture.com), QFD2000 (by Total Quality Software, UK: http://www.qfd2000.co.uk), Qualica QFD (by Qualica Software, Germany: http://www.qualica.de), and VOCALYST (by Applied Marketing Science, US: http://www.ams-inc.com). The readers are referred to Herzwurm et al. (1997, 2000) and Struebing (1996) for more QFD software tools and, in particular, to Herzwurm et al. (1997, 2000) for evaluations of them.

Third, a large amount of online QFD information is accessible. For example, a number of quality-related websites are listed in Anonymous (1999) and Cartin (1999). A QFD email discussion list (Clauson, 1996) is supported by Quality Resources Online (http://www.quality.org/lists/qfdl.info.txt) that also provides some QFD links (http://quality.org/html/qfd.html). A UK based QFD discussion forum is open at http://www.jiscmail.ac.uk/lists/qfd.html and much useful QFD information can be found at University of Sheffield's QFD homepage http://www.shef.ac.uk/~ibberson/qfd.html. In addition, about 20 of G.H. Mazur's QFD articles can be downloaded from his website: http://mazur.net, and a number of QFD articles by K. Crow and R. Hales are available online at the websites of their respective consulting firms, DRM Associates (http://www.npd-solutions.com) and ProAction Development (http://www.proactdev.com).

Fourth, a vast literature on QFD has been accumulated, including books, book chapters, theses, technical reports/working papers, and articles in edited volumes, conference proceedings, journals, and magazines. The features of this QFD literature are briefly summarized in the following sections.

3. Functional fields of QFD

QFD was originally proposed, through collecting and analyzing the voice of the customer, to develop products with higher quality to meet or surpass customer's needs. Thus, the primary functions of QFD are *product development*, *quality management*, and *customer needs analysis*. Later, QFD's functions had been expanded to wider fields such as *design*, *planning*, *decision-making*, *engineering*, *management*, *teamwork*, *timing*, and *costing*. Essentially, there is no definite boundary for QFD's potential fields of applications.

3.1. Product development

One of QFD's two popular application fields is *product development* (Ansari and Modarress, 1994; Anthony and Dirik, 1995; Bergquist and Abeysekera, 1996; Bode and Fung, 1998; Burrows, 1991; Cadogan et al., 1994; Crow, 1999; Govindaraju and Mital, 2000; Griffin, 1992; Gustafsson, 1996; Hales, 1993a, 1994; Hjort et al., 1992; Kaulio, 1998; Kealin and Klein, 1992; Maduri, 1992; Matzler and Hinterhuber, 1998; Rahman, 1995; Rodriguez-Soria, 1989; Scheurell, 1994; Schubert, 1989a,b; Shen et al., 2000a; Tottie and Lager, 1995; Tsuda, 1997; Vonderembse and Raghunathan, 1997; Zairi and Youssef, 1995; Zhang et al., 1999). There are also many similar and particular applications of QFD in this field, including the *development* of *courses/curriculums* (Bier and Cornesky, 2001; Cornesky, 1997; Richardson, 1997; Wiklund and Wiklund, 1999), *model-change products* (Hoque et al., 2000), *new products* (Dawson and Askin, 1999; Griffin, 1989; Hales and Staley, 1995; Holmen and Kristensen, 1998; Lockamy and Khurana, 1995a,b; Miller, 1998; Natter et al., 2001; Poolton and Barclay, 1996; Rangaswamy and Lilien, 1997; Rao et al., 1999; Rosas-Vega and Vokurka, 2000; Song et al., 1997; Tse, 1999;

Wallace, 1992; Walsh, 1990), *products and processes* (Verma et al., 1998b), *product concept* (Schmidt, 1997), *reliability test methods* (Kwon and Han, 1999), *softwares* (Barnett and Raja, 1995; Haag et al., 1996; Thackery and Van Treeck, 1990), *strategic performance metrics* (Hauser, 2001), and *systems* (Stubbs and Diaz, 1994; Stylianou et al., 1997).

3.2. Quality management

Another popular field of QFD's applications is *quality management* that is an important part of the QFD process and essential for successful product development, and many publications can be found in this field, such as Adiano (1998), Aly et al. (1990), Anjard (1995), Anonymous (1995c), Barnett (1991), Basili and Musa (1991), Beerten (1996), Bhote (1997b), Braunsperger (1996), Coate (1990), Cozart et al. (1990), Dale et al. (1998), Dalen (1996), Erikkson and McFadden (1993), Ermer (1995a), Finley (1992), Ghobadian and Terry (1995), Gopalakrishnan et al. (1992), Haavind (1989), Hames (1991), Hassan et al. (2000), Ho et al. (2000, 2001), Jones (1988), Karmarkar and Pitbladdo (1997), Koksal and Egitman (1998), Lam and Zhao (1998), Leung (1997), Lim and Tang (2000), Liu and Zhou (1996), Lockamy and Khurana (1995b), Lorenzen et al. (1993), Lyu and Gunasekaran (1993), Motwani et al. (1996), Nickerson (1993), Novack et al. (1993), Owlia and Aspinwall (1998), Price (1995), Pulat (1994), Radharamanan and Godoy (1996), Rahman (1995), Reynolds (1989), Rogers (1998), Stauss (1993), Tribus (1993), Wasserman et al. (1989), Yilmaz and Chatterjee (1997), and Zairi and Youssef (1995). In particular, QFD has been applied to *expert systems for quality management* (Bird, 1992), *process improvement* (Hybert, 1996; Richardson, 2001; Zaciewski, 1994), *quality control* (Acord, 1996; Erikkson and McFadden, 1993; Keenan, 1996; Koksal et al., 1992; Prasad, 1997), *quality information systems* (Chang, 1989; Lin and Fite, 1995), *quality systems* (Burn, 1994; Kanji, 1998), *service improvement* (Barnes and Vidgen, 2001; Curry, 1999; Curry and Herbert, 1998; Chin et al., 2001; Harvey, 1998; Hofmeister, 1995; Jeong and Oh, 1998), *service quality management systems*

(Chang and Lin, 1991), and *software process improvement* (Herzwurm et al., 2000).

3.3. Customer needs analysis

Quality management and *product development* are achieved in QFD through *customer needs analysis* that, in fact, is always the very first step of a QFD process and is thus an important functional field of QFD. Publications in this field are quite rich, focusing mainly on the two key aspects of customer needs analysis: *collecting/translating customer needs* (Bech et al., 1997; Bergquist and Abeysekera, 1996; Bhote, 1997a; Brown, 1991b; Brown and Harrington, 1994; Chaplin et al., 1999; Dalen, 1996; Dube et al., 1999; Griffin and Hauser, 1993; Gustafsson, 1993; Hales, 1993a; Hauser, 1993; Ho et al., 1999; Howell, 2000; Hunter and Van Landingham, 1994; Hwarng and Teo, 2001; Kenny, 1988; King, 1987a, 1994; Klein, 1990; Liu et al., 1998, 2001; Logan and Radcliffe, 1997; Mazur, 1991; McLaurin and Bell, 1991, 1993; Metha, 1994; Miller, 1998; Newman, 1988; Rajamanickam et al., 1998; Reed, 1995; Reid and Hermann, 1989; Schauerman et al., 1994; Schriefer, 1995; Senthil et al., 2001; Shillito, 1992b; Stevens, 1996; Stocker, 1991; Stratton, 1989; Sullivan, 1986a; Symons, 1991; Tan and Shen, 2000; Tan et al., 1998; Temponi et al., 1999; Vasilash, 1989; Viaene and Januszewska, 1999; Whiting, 1993) and *satisfying customer needs* (Anonymous, 1994a; Askin and Dawson, 2000; Curtis and Ellis, 1998; Denton, 1990b; Einspruch et al., 1996; Henderson, 1994; Jeong and Oh, 1998; Johnston and Burrows, 1995; Karbhari et al., 1994; Kenny, 1988; Lapidus and Schibrowsky, 1994; Mallon and Mulligan, 1993; Matzler and Hinterhuber, 1998; Motwani et al., 1996; Pogacnik and Kopac, 2000; Sandelands, 1994a; Shen et al., 2000a,b; Starbek et al., 2000; Stratton, 1989; Swackhamer, 1985; Taylor, 1997; Trappey et al., 1996; Wu and Wu, 1999; Yang et al., 2000). There are also QFD applications addressing some specific aspects of customer needs analysis, such as *customer involvement* (Huovila and Seren, 1998; Kaulio, 1998; Tottie and Lager, 1995), *customer preference* (Lai et al., 1998), *customer responsiveness* (Atkinson, 1990), *customer services* (Denton, 1990a; Graessel and Zeidler,

1993; Riffelmacher, 1991), *data collection* (Casey et al., 1993), *defining quality requirements* (Hauser and Klein, 1988; Hrones et al., 1993; LaSala, 1994), *processing client requirements* (Kamara and Anumba, 2000; Kamara et al., 1999, 2000), and *prioritising customer needs* (Persson et al., 2000).

3.4. Product design

QFD can be referred to as designed-in quality rather than traditional inspected-in quality in the sense that it helps a company shift from inspecting the product's quality to designing quality into the product through customer needs analysis (Guinta and Praizler, 1993). Therefore, *product design* is also a functional field of QFD as illustrated in Acord (1997), Bahrami (1994), Belhe and Kusiak (1996), Bodell and Russell (1989), Colton and Staples (1997), Conley (1998), De Vera et al. (1988), Elboushi and Sherif (1997), Filling et al. (1998), Fox (1993), Gershenson and Stauffer (1999), Halbleib et al. (1993), Harding et al. (1999, 2001), Karbhari et al. (1991), Kim and Moskowitz (1997), Logan and Radcliffe (1997), Moskowitz and Kim (1997), Nibbelke et al. (2001), Nichols and Flanagan (1994), Reed (1995), Reich (2000), Reich et al. (1996), Remich (1999), Rosenthal (1992), Steiner et al. (1992), Storen (1997), Swackhamer (1985), Wang (1999), Wei et al. (2000), Wu and Wu (1999), and Yang et al. (2000). There are a wealth of studies in this field focusing on the design of different products as well as on the different issues in product design, including *3D geometry-based product design* (Fuxin et al., 2001), *course design* (Burgar, 1994; Gustafsson et al., 1999), *design for manufacturability* (Fabricius, 1994; Youssef, 1994), *design methods* (Esteghlalian et al., 1998; Frank and Green, 1992; Hovmark and Norell, 1994; Huang and Mak, 1999, 2001; Killander, 2001; Sivaloganathan et al., 1995, 2001), *design of information systems and services* (Hallberg, 1999), *designing customer-driven marketing programs* (Mohr-Jackson, 1996), *engineering design* (Hazelrigg, 1996, 1998), *flight control design* (Joos, 1999), *housing design* (Abdul-Rahman et al., 1999), *information system design* (Hallberg et al., 1999b), *instructional design* (Murgatroyd, 1993), *internal service system design* (Natarajan et al.,

1999), *manufacturing system design* (Monplaisir et al., 1997), *process design* (Ferguson, 1990), *product concepting* (Burchill and Fine, 1997; Shillito, 1992b), *product definition* (Anonymous, 1995a; Aldrich and Stauffer, 1995; Hales, 1993a), *product/process innovation* (Presley et al., 2000; Voss, 1994), *product redesign* (Anonymous, 1993a; Hauser, 1993), *product/service introduction* (Nolle, 1993), *questionnaire design* (Glushkovsky et al., 1995), *robust design* (Kraslawski et al., 1993), *service design* (Ermer and Kniper, 1998; Franceschini and Terzago, 1998; Selen and Schepers, 2001; Stamm, 1992), *system design* (Dowlatshahi and Ashok, 1997; Chapman et al., 1992; Tan et al., 1998), *system redesign* (Goodstein and Butz, 1998), *training module design* (Shaffer and Pfeiffer, 1995), and *value design* (Shillito, 1992a).

3.5. Planning

QFD is a pro-active "customer-driven planning process" so that problems could be found and solved at the very beginning of the product development and fewer people have to deal with the problems at the later stages (Day, 1993). This idea of QFD is not only applicable to the usual *product planning* (Cohen, 1988; Ngai and Chow, 1999; Prasad, 1994) and *process planning* (Conti, 1989; Geiger and Steger, 1995; Price, 1995), but also applicable to *general planning* (Casey et al., 1993; Liu and Zhou, 1996; Khoo and Ho, 1996; Schubert, 1989b), *strategic planning* (Crowe and Cheng, 1996; Leung, 1997; Lyman et al., 1994; Maddux et al., 1991), and other specific types of planning. Examples include *business planning* (Ferrell and Ferrell, 1994), *business process planning* (Rajala and Savolainen, 1996), *nursing service planning* (Matsuda et al., 1998, 2000), *product-technology roadmap drafting* (Groenveld, 1997), *organization planning* (King, 1992), *research planning* (Kauffmann et al., 1999), *service quality planning* (Stuart and Stephen, 1996), *strategic marketing planning* (Lu and Kuei, 1995; Lu et al., 1994), *strategic research planning* (Chen and Bullington, 1993), *supply chain planning* (Li et al., 2001), *technical planning* (McLaughlin and Stratman, 1997), and *test planning* (Bardenstein and Gibson, 1992).

3.6. Engineering

Apart from the above five popular functions, QFD is also related to and can thus be applied to other fields. One such field is *concurrent engineering* (Anderson, 1993; Dowlatshahi and Ashok, 1997; Elshennawy et al., 1993; Hales, 1993c; Harding et al., 1999; Karbhari et al., 1994; Krishnaswamy and Elshennawy, 1992; Parr, 1995; Pohl and Jacobs, 1994; Stahl et al., 1997; Thomas, 1996; Tsuda, 1997; Veness et al., 1996; Williams, 1994; Zakarian and Kusiak, 1999). Specially, there have also been reported QFD linkages with *knowledge intensive engineering* (Reich, 1995), *quality engineering* (Charteris, 1993), *rehabilitation engineering* (Jacques et al., 1994), *requirements engineering* (Johansson and Timpka, 1996), *simultaneous engineering* (Schmidt, 1997), *strategic re-engineering* (Anonymous, 2001), *system engineering* (Brady, 2001; Maier, 1996), and *value engineering* (Brown, 1991a).

3.7. Decision-making

QFD determines product design specifications (hows) based on customer needs (whats) and competitive analysis (whys), which represents a customer-driven and market-oriented process for *decision-making*. It is quite natural to use QFD in this field for such purposes as *determining customer needs* (Stratton, 1989) and *development priorities* (Han et al., 1998), *formulating annual policies* (Philips et al., 1994) and *manufacturing strategies* (Crowe and Cheng, 1996; Jugulum and Sefik, 1998), *benchmarking* (Kochhar and Eguia, 1998; Kochhar and Saeed, 1999; Pfohl and Ester, 1999), and *environmental decision-making* (Berglund, 1993). Essentially, QFD has been widely applied to the major aspects of decision-making: *measurement*, *selection/determination*, and *evaluation*. Reported examples include *measuring customer satisfaction* (Motwani et al., 1996), *performance* (Ellis, 1998; Jagdev et al., 1997; Kochhar and Eguia, 1998; Kochhar and Saeed, 1999; Kutucuoglu et al., 2001; Lim et al., 1999; Roche and Jackson, 1994), *process* (Jacobs et al., 1995; Mrad, 1997, 1999), *productivity of technology* (Chiou et al., 1999), *quality costs* (Moen, 1998), and

quality of services (Van Looy et al., 1998); *selecting/determining composition of peacekeeping forces* (Partovi and Epperly, 1999), *concepts* (Kenny, 1988; Pugh, 1981), *design alternatives* (Delano et al., 2000; Cook and Wu, 2001), *optimal design requirements* (Park and Kim, 1998), *development priorities* (Han et al., 1998), *equipment* (Hales, 1995c; Lucas and Pilkington, 1995), *facility locations* (Chuang, 2001), *improvement priorities* (Barad and Gien, 2001), *marketing strategies* (Nagendra and Osborne, 2000), *optimal instrumentation* (Doyotte et al., 1999), *processes* (Mrad, 1997), *products* (Weiss and Butler, 1992), *R&D projects* (Curtis and Ellis, 1998), *service delivery priorities* (Curry, 1999), *team members* (Zakarian and Kusiak, 1999), *teaching methods* (Lam and Zhao, 1998), *technologies* (Beckwith and Hunter-Zaworski, 1998; Halog et al., 2001; Kim et al., 1997; Madu et al., 1994), *total quality strategies* (Smith and Angeli, 1995), and *TQM/BPR implementation plans* (Fazel and Salegna, 1996); and *evaluating company's current status* (Kumar and Midha, 2001), *degree courses* (Higgins et al., 1994), *information technologies* (Kim et al., 2000c), *MBA programs* (Pitman et al., 1996), *organizations* (Singh and Deshmukh, 1999), *product options* (Otto, 1995), *R&D projects* (Johnson, 1995), *strategic performance* (Adams et al., 1995), *suppliers* (Holmen and Kristensen, 1998), *system reliability* (Verma and Knezevic, 1996), *teaching methods* (Lam and Zhao, 1998), *technologies* (Lowe et al., 2000; Sarkis and Liles, 1995), and *value* (Housel and Kanevsky, 1995).

3.8. Management

All of the above reviewed functions of QFD are related to *management*, more or less. It is thus not surprising that QFD can be directly used as a *management tool* (Beerten, 1996; Cozart et al., 1990; Howell, 2000; McLaurin and Bell, 1991; Verganti, 1997; Walsh, 1990). In particular, QFD has been applied in this field to the *management* of *advanced manufacturing enterprises* (Ren et al., 1997), *business* (Flaig, 1992; Lee and Ko, 2000; Lee et al., 1998), *business processes* (Rajala et al., 1997), *capital budget* (Partovi, 1999), *culture* (Angeli et al., 1998; Hales, 1995b), *customer complaints*

(Lapidus and Schibrowsky, 1994), *customer–sup-plier relationships* (Kochhar and Saeed, 1999), *information infrastructure in small cities* (Khawaja and Benjamin, 1996), *maintenance* (Kutucuoglu et al., 2001), *manufacturing* (Anonymous, 1998; Boubekri et al., 1991; Conley, 1998), *organization's competitive advantages* (Bosserman, 1992; O'Neal, 1991), *policies* (Sullivan, 1988), *processes* (Conti, 1989), *programs* (Maddux et al., 1991), *projects* (Richardson, 2001), *radar-based position reporting systems* (Johnston and Burrows, 1995), *research portfolios* (Kauffmann et al., 1999, 2000), *risk* (Monplaisir et al., 1997), *road traffic accidents* (Sohn, 1999), *services* (Partovi, 2001), *supply chain* (Samuel and Hines, 1999; Sohn and Choi, 2001), *strategic performance* (Hauser, 2001), *strategies* (Ko and Lee, 2000), and *technologies* (Hequet, 1991).

3.9. Teamwork, timing, costing, and others

QFD's above-mentioned multi-functions dem-onstrate its usefulness, and its successful applica-tions have produced noticeable benefits such as the *promotion of teamwork*, the *provision of documen-tation*, *shorter design cycles*, and *lower start-up cost* (Abdul-Rahman et al., 1999; American Supplier Institute, 1994; Bossert, 1991; Griffin and Hauser, 1993; Hauser and Clausing, 1988; Sullivan, 1986b; Vonderembse and Raghunathan, 1997). Specifi-cally, QFD is beneficial to *cross-functional coop-eration* (Song et al., 1997), *improving product development cycles* (Sansone and Singer, 1993), *improving the visualization of the design attributes* (Hallberg et al., 1999a), *information sharing/inter-nal communications* (Griffin and Hauser, 1992, 1996; Harding et al., 1999, 2001; Pohl and Jacobs, 1994; Sandelands, 1994b), *just-in-time* (Natarajan and Weinrauch, 1990; Prasad, 1995a,b), *problem prevention* (Clausing and Simpson, 1990; Stauss, 1993), *reducing cost* (Haavind, 1989; Chaplin and Terninko, 2000), *reducing product definition/intro-duction/development time* (Kerr, 1989; Rosas-Vega and Vokurka, 2000; Sansone and Singer, 1993; Sim and Curatola, 1999), *representation for design information* (Aldrich and Stauffer, 1995), *repre-senting qualitative management information* (Dag-ersten et al., 1998), *resource allocation* (Colton and

Staples, 1997), *synthesis of market research data* (Prasad, 1998b), *target costing* (Booth, 1995; Lopez-Gonzalez, 2001), and *teamwork* (Anony-mous, 1994b; Frank and Green, 1992; Griffin and Hauser, 1992; Lyman and Richter, 1995; Sande-lands, 1994b; Schonberger, 1994).

4. Applied industries of QFD

The first two reported applications of QFD were in the *shipbuilding* (Nishimura, 1972) and *electronics* (Akao, 1972) industries. QFD's early applications focused on such industries as *auto-mobiles*, *electronics*, and *softwares*. The fast de-velopment of QFD has resulted in its applications to many *manufacturing* industries. Eventually, QFD has also been introduced to the *service* sector such as *government*, *banking and accounting*, *health care*, *education and research*. Now it is hardly to find an industry to which QFD has not yet been applied.

4.1. Transportation and communication

Shipbuilding is one of the two earliest QFD application sectors (Nishimura, 1972), and Lyu and Gunasekaran (1993) report another such QFD application. *Automobile* is an earlier and impor-tant industry to which many authors report their QFD applications (Anderson, 1993; Anonymous, 1989, 1994a; Colton and Staples, 1997; De Vera et al., 1988; Dika, 1995; Ferguson, 1990; Fuxin et al., 2001; Gilmore, 1992; Ginn et al., 1998; Keenan, 1996; Lockamy and Khurana, 1995a,b; Sandelands, 1994a; Schaal and Slabey, 1991; Stratton, 1989; Thomas, 1996; Tsuda, 1997; Wang, 1999). QFD applications can also be found in *aircraft* (Delano et al., 2000), *airlines* (Ghobadian and Terry, 1995), *automotive parts* (Liker et al., 1996), *car audio* (Ngai and Chow, 1999), *com-mercial vehicles* (Franceschini and Rupil, 1999), *container port* (Johnston and Burrows, 1995), *motors* (Taylor, 1997), *railways* (Herrmann et al., 2000; Leung, 1997), *pedestrian crossings* (Beckwith and Hunter-Zaworski, 1998), *satellite* (Ho, 2000), *(tele)communications* (Brown, 1991b; Brown and Harrington, 1994; Kim et al., 1997; Nolle, 1993;

Sansone and Singer, 1993), *transportation* (Henderson, 1994), *transportation equipment* (Bodell and Russell, 1989; Conley, 1998), and *voice mail systems* (Hales, 1995c).

4.2. Electronics and electrical utilities

Akao (1972) applies QFD to *electrostatic copying machines* and thus makes *electronics* another earliest QFD application sector. QFD has been applied to such electronics-related companies as *AT&T* (Brown, 1991b; Brown and Harrington, 1994; Nolle, 1993; Sansone and Singer, 1993), *DEC* (Cohen, 1988; Van Treeck and Thackeray, 1991), *Hewlett-Packard* (Haavind, 1989; Thompson and Chao, 1990; Williams, 1994), *IBM* (Adiano and Roth, 1994; Hequet, 1991; Sharkey, 1991; Wood, 1998), *Intel* (Kerr, 1989), *Motorola* (Bosserman, 1992), and *Philips* (Groenveld, 1997), and to electronics-related products/parts such as *automated teller machines* (Riffelmacher, 1991), *blend door actuators* (De Vera et al., 1988), *chip* (Metha, 1994), *climatic control systems* (Franceschini and Rupil, 1999), *computers* (Cohen, 1988; Rosas-Vega and Vokurka, 2000), *hard disk drives* (Mrad, 1997, 1999), *integrated circuit* (Philips et al., 1994), *robotic workcell* (Yang et al., 2000), and *sensor* (Beckwith and Hunter-Zaworski, 1998; Maier, 1996). Other QFD applications in electronics include Aly et al. (1990), Burrows (1991), Denton (1990a), Flaig (1992), Glushkovsky et al. (1995), Hequet (1991), Lucas and Pilkington (1995), Nichols and Flanagan (1994), Tse (1999), and Whiting (1993). QFD has also been applied to *electrical utilities* such as *battery* (Halbleib et al., 1993), *Florida Power and Light* (Hofmeister, 1995), *gas burners* (Remich, 1999), *Pacific Gas and Electric* (Tessler et al., 1993), *power systems* (Rajala and Savolainen, 1996), and *wind turbines* (Schmidt, 1997).

4.3. Software systems

Another early popular sector of QFD applications is *software systems*. Especially, there are many reported QFD applications in *software*, such as Anonymous (1993b), Barnett and Raja (1995), Basili and Musa (1991), Brown (1991b), Chang

(1989), Elboushi and Sherif (1997), Haag et al. (1996), Haavind (1989), Herzwurm et al. (1997, 2000), Karlsson (1997), Kekre et al. (1995), Liu et al. (1998), Liu (2001), Ouyang et al. (1997), Richardson (2001), Roche and Jackson (1994), Thackery and Van Treeck (1990), Xiong and Shindo (1995), Yilmaz and Chatterjee (1997), Yoshizawa et al. (1990), Zhou (1998), and Zultner (1990, 1992). Other related QFD application areas include *decision support systems* (Sarkis and Liles, 1995), *expert systems* (Ngai and Chow, 1999), *human–machine interface* (Nibbelke et al., 2001), *information systems* (Chang and Lin, 1991; Erikkson and McFadden, 1993; Han et al., 1998), *integrated systems* (Wasserman et al., 1989), *management information systems* (Eyob, 1998), *profiling systems* (LaSala, 1994), and *Web pages* (Tan et al., 1998).

4.4. Manufacturing

Manufacturing is also an earlier area of QFD applications, which can be found, e.g., in the earlier papers of Sullivan (1986b) and Swackhamer (1985). Along with its fast development, there have been more and more QFD applications in manufacturing (Atkinson, 1990; Bahill and Chapman, 1993; Barad and Gien, 2001; Barnett, 1991; Bird, 1992; Clausing and Simpson, 1990; Denton, 1990b; Gipprich, 1987; Hales, 1993a, 1994; Hunter and Van Landingham, 1994; Jugulum and Sefik, 1998; Karmarkar and Pitbladdo, 1997; Khoo and Ho, 1996; King, 1992; Kinni, 1993; Kochhar and Eguia, 1998; Krishnaswamy and Elshennawy, 1992; Morrell, 1987; Pulat, 1994; Youssef, 1994). QFD has also been applied to diversified manufacturing areas, such as *assembly lines/plants/stations* (Adiano and Roth, 1994; Mrad, 1997, 1999), *bearing* (Anonymous, 1993a), *braking systems* (Nickerson, 1993), *capital goods* (Lucas and Pilkington, 1995; Pfohl and Ester, 1999), *chocolate* (Viaene and Januszewska, 1999), *composite material* (Karbhari et al., 1991), *computer-integrated manufacturing* (Boubekri et al., 1991), *cork removers* (Reich, 1996), *engine filters* (Zhang et al., 1999), *equipment* (Maduri, 1992; Matzler and Hinterhuber, 1998; Scheurell, 1994), *food* (Charteris, 1993; Costa et al., 2000), *furniture* (Acord,

1996, 1997), *helmet-mounted displays* (Cadogan et al., 1994), *hybrid bicycles* (Govindaraju and Mital, 2000), *instrumentation* (Rice, 1989), *meat* (Dalen, 1996), *medical devices* (Hauser, 1993; Kealin and Klein, 1992; Rodriguez-Soria, 1989), *metals* (Crowe and Cheng, 1996; Schriefer, 1995; Tottie and Lager, 1995), *metrology probes* (Parr, 1995), *pea* (Bech et al., 1997), *pencils* (Askin and Dawson, 2000), *plastic components* (Yeung and Lau, 1997), *power protection equipment* (Gershenson and Stauffer, 1999), *printing* (Cozart et al., 1990; Finley, 1992), *pultruders* (Steiner et al., 1992), *quick release top nozzles* (Crow, 1999), *safety shoes* (Bergquist and Abeysekera, 1996), *tea* (Wu and Wu, 1999), and *tractors* (Reed, 1995).

4.5. Services

QFD is a customer-oriented quality management and product development technique originally used for hard products, but its ideas are by no means inapplicable to soft services. Indeed, it was gradually introduced into the service sector to design and develop quality *services* (American Supplier Institute, 1992d, 1994; Anonymous, 1995b; Behara and Chase, 1993; Chang and Lin, 1991; Ermer and Kniper, 1998; Harvey, 1998; Hofmeister, 1992, 1995; Kaneko, 1991; Natarajan et al., 1999; Partovi, 2001; Stamm, 1992; Stauss, 1993; Tessler et al., 1993). The wide acceptability of the QFD technique can be shown from its reported applications in various service areas such as *accounting* (Booth, 1995), *administration* (Hofmeister, 1992), *banking* (Ko and Lee, 2000; Riffelmacher, 1991), *contracting process* (Bersbach and Wahl, 1990; Hybert, 1996), *engineering services* (Pun et al., 2000), *food distribution* (Samuel and Hines, 1999), *government services* (Lewis and Hartley, 2001), *hotels* (Dube et al., 1999; Stuart and Stephen, 1996), *on-line bookshops* (Barnes and Vidgen, 2001), *mortgage* (McLaurin and Bell, 1991, 1993), *professional services* (Adiano, 1998), *public sectors* (Curry, 1999; Curry and Herbert, 1998; Ellis, 1998; Hallberg, 1999), *real estate appraisal* (Ferrell and Ferrell, 1994), *retail* (Nagendra and Osborne, 2000; Trappey et al., 1996), *technical library and information services* (Chin et al., 2001; Leung, 1997), *wholesale* (Keenan, 1996; Lin and

Fite, 1995) and, in particular, *healthcare* (Chaplin et al., 1999; Chaplin and Terninko, 2000; Einspruch et al., 1996; Hallberg et al., 1999a,b; Hauser, 1993; Jeong and Oh, 1998; Johansson and Timpka, 1996; Kaminski et al., 1992; King, 1994; Lim and Tang, 2000; Lim et al., 1999; Logan and Radcliffe, 1997; Matsuda et al., 1998, 2000; Radharamanan and Godoy, 1996; Shaffer and Pfeiffer, 1995).

4.6. Education and research

Among the broad service areas, academic organization is a special one that has witnessed a number of QFD applications to conduct quality education and research based on QFD's customer-driven planning principles. In the educational area, QFD's applications include *colleges/universities* (Bier and Cornesky, 2001; Burgar, 1994; Chen and Bullington, 1993; Coate, 1990; Ermer, 1995a; Higgins et al., 1994; Jaraiedi and Ritz, 1994; Koksal and Egitman, 1998; Lam and Zhao, 1998; Owlia and Aspinwall, 1998; Richardson, 1997; Wiklund and Wiklund, 1999), *distance education* (Murgatroyd, 1993), *educational institutes* (Cornesky, 1997; Singh and Deshmukh, 1999), *kindergartens* (Moura and Saraiva, 2001), *public schools* (Tribus, 1993), *training* (Franceschini and Terzago, 1998; Hequet, 1991; Ho, 2000; Zaciewski, 1994), *vocational secondary schools* (Starbek et al., 2000) and, interestingly, *business schools* (Hwarng and Teo, 2001; Motwani et al., 1996; Novack et al., 1993; Pitman et al., 1996). QFD has also been applied to *R&D* (Curtis and Ellis, 1998; Delano et al., 2000; Moenaert and Caeldries, 1996; Takahashi, 1997) and *research program design* (Kauffmann et al., 1999).

4.7. Other industries

QFD's principles set no prerequisites about the types of the products/services and the producing/serving organizations. Indeed, the applications of QFD are industry free and, beyond the above six general industries, QFD has also attracted the attention from many other industries such as *aerospace* (Chi, 1990; Dean, 1992; Jacobs et al., 1994; Stubbs and Diaz, 1994; Weiss and Butler, 1992), *agriculture* (Reed, 1995), *beautiful enterprises* (Chan,

2000), *construction* (Abdul-Rahman et al., 1999; Armacost et al., 1994; Huovila and Seren, 1998; Kamara and Anumba, 2000; Kamara et al., 1999, 2000; Mallon and Mulligan, 1993; Pheng and Yeap, 2001), *disaster prevention* (Kara-Zaitri, 1996), *environment protection* (Berglund, 1993; Halog et al., 2001; Zhang et al., 1999), *indoor air quality* (Park and Kim, 1998), *management culture* (Angeli et al., 1998), *military* (Filling et al., 1998; Jacobs et al., 1995; Maddux et al., 1991), *national security* (Mann and Halbleib, 1992), *packaging* (Li et al., 2001; Raper, 2000), *peacekeeping forces* (Partovi and Epperly, 1999), *police stations* (Selen and Schepers, 2001; Sohn, 1999), *political elections* (Mevorach, 1997), *socio-economic development* (Madu and Kuei, 1994), *technologies* (Anthony and Dirik, 1995; Chiou et al., 1999; Karbhari et al., 1994; Madu and Kuei, 1994; Sarkis and Liles, 1995), and *textile* (Koksal et al., 1992; Rajamanickam et al., 1998; Temponi et al., 1999).

5. Methodological development of QFD

Loosely defined and structured, QFD sometimes becomes an art more than a science, which makes it difficult for practitioners to use QFD. However, there have recently appeared many *methodological works* on QFD to make it more rigorous and operational, such as *analysis tools to enhance QFD* (Mill, 1994), *detailed framework for Phase 3 of QFD* (Florusse and Clausing, 1992), *methods for improving the use of QFD* (Franceschini and Rossetto, 1998), *recent approaches of QFD* (Akao, 1994; Mazur, 1991), and *study of the relationships among quality's ends and means in QFD* (Georgantzas and Hessel, 1995). These works are briefly summarized below for practitioners to understand and apply QFD in a more objective and precise way.

5.1. Quantitative methods for QFD

Various *quantitative methods* have been suggested to use in QFD to improve its reliability and objectiveness, noticeably the methods of *management science/operational research (MS/OR)*, *marketing research*, and *fuzzy logic*. Works applying

MS/OR methods to QFD include *analytic hierarchy process (AHP) to prioritize customer needs (whats)* (Armacost et al., 1994; Chuang, 2001; Madu and Kuei, 1994), *AHP and benchmarking integrated to rate "whats"* (Lu et al., 1994), *AHP and QFD for combining customers' requirements and preferences* (Lin and Fite, 1995), *AHP and two multi-attribute decision-making methods for rating "whats"* (Chan and Wu, 1998), *AHP, multi-attribute utility theory, and linear programming methods for rating "whats"* (Ho et al., 1999), *value functions to capture "whats"* (Askin and Dawson, 2000), *AHP to study the ranking sensitivity of "whats" in QFD* (Xie et al., 1998); *0–1 goal programming model for selecting product design specifications (hows)* (Han et al., 2001), *AHP and mathematical programming to select team members* (Zakarian and Kusiak, 1999), *AHP combined with QFD to identify teaching methods* (Lam and Zhao, 1998) and *select technologies* (Madu et al., 1994), *entropy method for prioritizing "hows"* (Chan et al., 1999), *mathematical programming model for determining the optimal values of "hows"* (Askin and Dawson, 2000; Belhe and Kusiak, 1996), *modelling procedure to set targets for "hows"* (Kim and Moskowitz, 1997), *MS/OR methods for analysing "hows"* (Wasserman, 1993), *multi-criteria decision aid method for prioritising "hows"* (Franceschini and Rossetto, 1995), *non-linear mathematical program for determining the optimal "hows" during new product development* (Dawson and Askin, 1999), *optimization model to minimize the ranking variability of "hows"* (Shen et al., 1999), *three MS/OR methods for prioritizing design rules* (Lee and Kusiak, 2001); *comparative study of the prioritization matrix and AHP methods in QFD* (Wang et al., 1998), *reducing the size of QFD matrixes using design decomposition approaches* (Kim et al., 1997; Shin and Kim, 2000), *group decision-making techniques for QFD* (Lai et al., 1998), *integrated mathematical programming formulation of QFD* (Moskowitz and Kim, 1997), *min–max parameter optimization in QFD* (Joos, 1999), *mix integer program for implementing QFD* (Zhou, 1998), *AHP* (Partovi, 1999, 2001; Partovi and Epperly, 1999) and *multi-attribute decision method* (Park and Kim, 1998) *for rating relations between "whats" and "hows"*, *multiobjective optimization*

for qualitative information in QFD (Locascio and Thurston, 1998), *optimisation in QFD* (Lee, 1995), *optimization models for identifying consensus rankings/ratings in QFD* (Vairaktarakis, 1999), *QFD combined with S-curve analysis for technical planning* (McLaughlin and Stratman, 1997), *role of Taguchi methods and design of experiments in QFD* (Ross, 1988), and *weighted additive decomposition model embedded into QFD* (Johnson, 1995).

Marketing research methods applied to QFD include *collecting customer needs by videotaping* (Logan and Radcliffe, 1997) and *seventeen steps* (Matsuda et al., 1998), *conjoint analysis* (Gustafsson et al., 1999), *customer satisfaction benchmarking process in QFD* (Shen et al., 2000b), *intensity-polarity voting model to generate group positions* (Coman, 2000), *marketing's lead role in QFD* (O'Neal and LaFief, 1992), *marketing procedure combining aggregate complaint analysis and QFD* (Lapidus and Schibrowsky, 1994), *marketing research methods for collecting and analysing "whats" in QFD* (Cristiano et al., 2000; Griffin and Hauser, 1993; Havener, 1993; Viaene and Januszewska, 1999), *marketing's role in the voice of the customer research* (Morris and Morris, 1999), *methods for adapting QFD to the US culture* (Hales, 1995a), *to a company's culture* (Hales, 1995b), and *to software* (Sharkey, 1991; Zultner, 1990), *new technologies for listening to the voice of the customer* (Klein, 1990), *nominal group technique sessions and interviews to define "whats"* (Jaraiedi and Ritz, 1994), *online surveys to obtain rankings of "whats"* (Tan et al., 1998), *personality types of QFD teams and QFD's efficiency* (Lyman and Richter, 1995), *questionnaire survey to testing critical "whats"* (Hunter and Van Landingham, 1994), *regression analysis to examine the effects of some factors on QFD applications* (Cristiano et al., 2001), *statistically fitted data as input to QFD* (Sohn, 1999), and *using Internet messages to supplement the QFD process* (Finch and Luebbe, 1997).

Fuzzy logic methods have also been used in QFD to deal with the subjectivity and ambiguity of evaluations on the "whats" and "hows" involved (Bouchereau and Rowlands, 1999; Harding et al., 2001; Lee, 1995; Liu et al., 1998; Lopez-Gonzalez, 2001; Masud and Dean, 1993; Verma

et al., 1998a, 1999). Particular works include *fuzzy inference-based QFD to determine design targets* (Fung et al., 1998, 1999), *fuzzy logic-based extension to QFD* (Temponi et al., 1999), *fuzzy logic-based simplification of QFD* (Kalargeros and Gao, 1998), *fuzzy method for prioritizing "hows" in QFD* (Chan et al., 1999), *fuzzy multicriteria methods for QFD* (Kim et al., 2000a; Sohn and Choi, 2001), *fuzzy optimization in QFD* (Kraslawski et al., 1993; Moskowitz and Kim, 1993), *fuzzy outranking approach to prioritize "hows" in QFD* (Wang, 1999), *fuzzy QFD framework* (Bahrami, 1994; Khoo and Ho, 1996; Shen et al., 2001), *fuzzy QFD mechanism for assessing system reliability* (Verma and Knezevic, 1996), *fuzzy QFD model for deriving optimal target values of "hows"* (Vanegas and Labib, 2001a), and *fuzzy ranking procedure for implementing QFD* (Zhou, 1998).

5.2. Extensions and implementation issues of QFD

A number of *QFD extensions* or modifications have been made to make QFD more representative and workable. Such works include *combining QFD and failure mode effects analysis* (Ginn et al., 1998), *comprehensive QFD* (Gustafsson, 1995; Nakui, 1991), *computational QFD* (Reich, 1995, 1996), *concurrent function deployment extending QFD's "quality plans" to several lifecycle "value sets"* (Prasad, 1998a, 2000), *cost, reliability, and technology incorporated into QFD* (Akao et al., 1983), *design costs integrated into QFD to optimize product development resources* (Bode and Fung, 1998), *distributed QFD* (Hrones et al., 1993; Ouyang et al., 1997), *dynamic QFD with feedback loops* (Adiano and Roth, 1994), *enhanced QFD* (Burchill and Fine, 1997; Clausing and Pugh, 1991), *expert system-based extension to the fuzzy QFD methodology* (Verma et al., 1998a), *extended QFD* (Hales et al., 1994; Herrmann et al., 2000; Prasad, 1998a), *extended QFD process for ecologically sustainable product design* (Storen, 1997), *four-stage model for performing software-oriented QFD* (Barnett and Raja, 1995), *fuzzy logic, artificial neural networks, and the Taguchi method combined with QFD to resolve its drawbacks* (Bouchereau and Rowlands, 2000a), *green QFD – integrating life cycle costing/assessment into QFD* (Zhang et al., 1999),

hierarchical framework for QFD planning process (Han et al., 2001), *including corporate requirements to form a broader QFD for product design* (Gershenson and Stauffer, 1999), *integrating Kano's model of customer satisfaction into QFD* (Matzler and Hinterhuber, 1998; Shen et al., 2000a; Tan and Shen, 2000), *integrating QFD, AHP and 0–1 integer programming for capital budgeting* (Partovi, 1999), *integrating QFD, AHP and benchmarking for service management* (Partovi, 2001), *integrating QFD and data envelopment analysis for research management* (Kauffmann et al., 2000), *integrating reliability into QFD* (Schubert, 1989a), *integrating the S-Model into QFD* (Cook and Wu, 2001), *medical software quality deployment* (Hallberg et al., 1999b), *modifications of QFD for collecting "whats"* (Dube et al., 1999), *modified QFD for "invisible" or performance-undifferentiating products* (Hales, 1993b), *modified QFD for services* (Stuart and Stephen, 1996), *integrating QFD and target costing* (Brusch et al., 2001; Hales and Staley, 1995), *process orientated improvement of QFD* (Schmidt, 1997), *QFD combined with value engineering and value graph techniques* (Prasad, 1998b), *QFD integrated with object oriented software design methodologies* (Lamia, 1995), *QFD integrated with software engineering* (Betts, 1990), *reusability integrated into enhanced QFD* (Witter et al., 1995), *service design QFD methodology by a 3-matrix approach* (Ermer and Kniper, 1998), *service QFD* (American Supplier Institute, 1994), *software QFD* (Haag et al., 1996; Liu, 2001; Ouyang et al., 1997; Yilmaz and Chatterjee, 1997), and *statistically extended QFD* (Rajala and Savolainen, 1996).

QFD's practical issues have been well discussed to increase the usability of QFD, such as *conditions and prerequisites to effective QFD* (Kinni, 1993), *difficulties and issues associated with QFD* (Dale et al., 1998), *effects of different deployment teams of QFD on quality and cost in product development* (Hoque et al., 2000), *factors for successful implementation of QFD* (Norman et al., 1991), *how QFD can be used and some of its problems* (Bouchereau and Rowlands, 2000b; Hazelrigg, 1996, 1998; Housel and Kanevsky, 1995; Lowe and Ridgway, 2000b; Nichols and Flanagan, 1994; Pheng and Yeap, 2001; Scheurell, 1994), *how to capture true customer needs* (Liu et al., 2001), *how to analyze conflicting customer needs* (Liu et al., 1998), *how to use templates to eliminate repetitive project setup in QFD/Capture* (Grace, 1996), *implementation issues of QFD* (Dickinson, 1995; Govers, 1996; Pandey, 1992; Reed et al., 1994; Vonderembse and Raghunathan, 1997), *implications of research results for QFD* (Kekre et al., 1995), *key factors in the successful application of QFD* (Cristiano et al., 2001), *market-research techniques need to be integrated into QFD* (Ball, 1995; Ermer, 1995b), *measurement scales of QFD* (Otto, 1995), *performing QFD step by step* (Crow, 2000), *prerequisites for succeeding with QFD* (Karlsson, 1997), *QFD implementation framework for beautiful enterprise* (Chan, 2000), *recommendations and a framework for the specific use of QFD by service firms* (Ghobadian and Terry, 1995), *relatively minor and short-term impacts of QFD on product development and suggestions for improvement in US firms* (Griffin, 1992), *systems approach to implementing QFD* (Kathawala and Motwani, 1994), *rating scales and their effects on priority rank of "hows"* (Franceschini and Rupil, 1999), *three groups of QFD implementation problems* (Govers, 2001), and *user's guide to QFD* (Lowe and Ridgway, 2000a).

Especially, information systems or *decision support systems (DSSs) for QFD* have been proposed for easy presentation and implementation of QFD. Related works include *computational support tools for QFD in a graph-based modeling environment* (Reich, 1995, 1996), *computerized QFD system* (Trappey et al., 1996), *expert system for constructing/classifying/managing house of quality charts in QFD* (Kim et al., 1998), *expert system-based extension to fuzzy QFD* (Verma et al., 1998a), *fuzzy expert system with spreadsheet to QFD* (Lopez-Gonzalez, 2001), *fuzzy information system for QFD* (Harding et al., 2001), *fuzzy logic-based intelligent tool for QFD* (Liu et al., 1998), *group DSS for applying QFD* (Wolfe, 1994), *group support systems for improving QFD process* (Balthazar and Gargeya, 1995), *heuristic inference scheme to reason about the implicit relationships between requirements in QFD* (Temponi et al., 1999), *information system for QFD implementation* (Sriraman et al., 1990), *integrated group decision-making system for QFD to rate "whats"* (Ho et al.,

1999), *intelligent DSS for QFD* (Bird, 1997), *intelligent hybrid system of QFD, AHP, and fuzzy set theory* (Fung et al., 1998), *Internet-based QFD* (Herzwurm et al., 2000), *neural networks for determining/interpreting the plentiful data in QFD* (Zhang et al., 1996), *networked QFD* (Brown, 1992), *novice-friendly QFD DSS for product design* (Moskowitz and Kim, 1997), *PC spreadsheet software for QFD* (Kalargeros and Gao, 1998), *QFD DSS* (Kim and Moskowitz, 1997; Omar et al., 1999), and *QFD-PC system with user interface* (Johnston and Burrows, 1995).

5.3. Comparative studies, surveys and reviews on QFD

Comparative studies as well as surveys and reviews on QFD have also been conducted to enhance the popularity of QFD. *QFD comparative studies* include *case-based comparison of two QFD models for product development* (Tsuda, 1997), *comparison of communication patterns of two new product development teams with and without QFD* (Griffin and Hauser, 1992), *comparison of QFD and decision analysis for making multi-objective product design decisions* (Delano et al., 2000), *comparison of QFD and other concurrent engineering tools used in UK industry* (Veness et al., 1996), *comparison of QFD and other methods for generating valid customer needs* (Brown and Harrington, 1994), *comparison of QFD and other new product development procedures* (Poolton and Barclay, 1996), *comparison of QFD and other software measurement methods* (Roche and Jackson, 1994), *comparison of QFD uses and benefits in the US and Japan* (Cristiano et al., 2000), *comparison of traditional QFD and multi-criteria decision aid-based QFD* (Franceschini and Rossetto, 1995), *differences between the Japanese and Western QFD practices* (Govers, 2001), *effects of incentive schemes and organizational structures on new product development process of firms with and without QFD* (Natter et al., 2001), *examination of some key issues in QFD and other quality management tools* (Dale et al., 1998), *functional relationship between QFD and value engineering* (Lyman, 1994), *relationship among QFD, target costing, and value engineering* (Wood, 1998), *rela-*

tionship between QFD and knowledge management (Nagai, 2001), *QFD and conjoint analysis* (Gustafsson, 1993), *QFD and the SERVQUAL model* (Curry and Herbert, 1998), *QFD, performance analysis, and structured methods* (Maier, 1993), and *quality deployment and cost deployment* (Maekawa and Ohta, 1990).

QFD surveys and reviews include *bibliography review of QFD and other quality techniques* (Anjard, 1993), *development of suppliers' role in QFD* (Ansari and Modarress, 1994), *full exploration and discussion of QFD through several case studies* (Zairi and Youssef, 1995), *history of QFD in Japan* (Akao, 1990b), *QFD discussion list* (Clauson, 1996), *QFD literature review and survey and analysis of more than 400 firms using QFD in the US and Japan* (Cristiano et al., 2000), *QFD practice outside North America* (Mazur, 1994), *QFD review* (Akao, 1997; Prasad, 1998a), *QFD survey of 33 firms and results* (Ettlie, 1993), *recent aspects of QFD in Japanese software industry* (Yoshizawa et al., 1993), *review of QFD and its applications* (Kathawala and Motwani, 1994; Sivaloganathan and Evbuomwan, 1997), *review of QFD and its customary practice around the world* (Bouchereau and Rowlands, 2000b), *review of QFD and its practice in the Netherlands* (Govers, 1996), *review of QFD and other methods for customer involvement in product development* (Kaulio, 1998), *review of QFD in the food industry* (Costa et al., 2000), *survey and analysis of 35 QFD projects at nine US firms* (Griffin, 1992), *survey and analysis of QFD's applications in US automotive industry* (Gilmore, 1992), *survey and analysis of QFD's uses, benefits, and implementation problems in the UK* (Martins and Elaine, 2001), *survey of 80 QFD projects and analysis of QFD's benefits and implementation issues* (Vonderembse and Raghunathan, 1997), *survey of 83 US electronic plants in dealing with time-based performance with and without QFD* (Sim and Curatola, 1999), *survey of 92 Japanese and 119 US automotive parts suppliers on the use of QFD* (Liker et al., 1996), *survey of 207 Japanese manufacturing firms to examine the effects of designers' participation in QFD* (Hoque et al., 2000), *survey of QFD's usage in software development* (Haag et al., 1996), and *user survey and evaluation of QFD softwares* (Herzwurm et al., 1997).

6. Ten informative QFD publications

The QFD literature is vast, and even the admittedly incomplete references we provide in this paper are many enough to make readers' choices difficult. It is thus useful to list a few informative QFD publications to facilitate the easy references of readers, especially of those who are not yet familiar with QFD. Quite subjectively, we suggest the following 10 frequently referred publications with comprehensive coverage of QFD's historical, conceptual, methodological and practical aspects:

1. Bahill, A.T., Chapman, W.L., 1993. A tutorial on quality function deployment. Engineering Management Journal 5 (3), 24–35.
2. Cohen, L., 1995. Quality Function Deployment: How to Make QFD Work for You. Addison-Wesley, Reading, MA.
3. Cristiano, J.J., Liker, J.K., White III, C.C., 2000. Customer-driven product development through quality function deployment in the US and Japan. Journal of Product Innovation Management 17 (4), 286–308.
4. Day, R.G., 1993. Quality Function Deployment: Linking a Company with Its Customers. ASQC Quality Press, Milwaukee, WI.
5. Govers, C.P.M., 1996. What and how about quality function deployment (QFD). International Journal of Production Economics 46–47 (December), 575–585.
6. Hauser, J.R., Clausing, D., 1988. The house of quality. Harvard Business Review 66 (3), 63–73.
7. Hill, A., 1994. Quality function deployment. In: Lock, D. (Ed.), Gower Handbook of Quality Management, second ed. Gover, Brookfield, VT, pp. 364–386 (Chapter 21).
8. Prasad, B., 1998a. Review of QFD and related deployment techniques. Journal of Manufacturing Systems 17 (3), 221–234.
9. ReVelle, J.B., Moran, J.W., Cox, C.A., 1998. The QFD Handbook. Wiley, New York.
10. Sullivan, L.P., 1986b. Quality function deployment. Quality Progress 19 (6), 39–50.

7. Summary

Over three decades have passed since Japanese academics and industries began to formalize the QFD technique in the late 1960s and early 1970s. Due to its effectiveness in product development and quality management, many QFD applications and studies have been reported. Through searching various sources, we have established an admittedly incomplete but hopefully useful QFD reference bank based on which a QFD literature review is conducted in this paper. In particular, we present a brief review of QFD's historical development and a categorical analysis of QFD's functional fields, applied industries and methodological development to facilitate the reference needs of QFD researchers and practitioners. We intend to update this literature review in both completeness of coverage and appropriateness of categorization in the future to better serve the QFD world, and hence any provision of QFD related information with the authors would be much welcome and highly appreciated.

8. For further reading

The following references are also of interest for the reader.

Adams and Gavoor (1990), American Supplier Institute (1992a), American Supplier Institute (1992b), American Supplier Institute (1992c), Anonymous (1993c), Anumba and Evbuomwan (1997), Aswad (1989), Badiru and Ayeni (1993), Bahill (1996), Band and Huot (1990), Barnard and Wallace (1994), Besterfield et al. (1999), Bicknell and Bicknell (1995), Carpinetti et al. (2000), Christensen et al. (1996), Christensen et al. (1999), Clausing (1988), Clausing (1994), Corbitt et al. (2000), Crow (1996), Crozier (1995a), Crozier (1995b), Daetz et al. (1995), Eccles (1994), Eureka (1987), Eureka and Ryan (1994), Eureka and Ryan (1995), Farrell (1994), Fortuna (1988), Foster (2001), Frew (1992), Frost (1999), Fuller (1998), Gevirtz (1994), Ghahramani and Houshyar (1996), Gong et al. (2000), Gould (2000), Green (1992), Grupp and Maital (1998), Haapalainen et al.

(2000), Hauser (1995), Herrmann and Huber (2000), Himmelfarb (1992), Howell (2000), Hunt (1993), Jackson and Frigon (1994), Jackson and Jones (1996), Jarvis (1999), Kennerfalk and Klefsjo (1995), Kim et al. (2000b), Kim et al. (1997), Kim et al. (2001), King (1987b), King (1995), Kolarik (1995), Madu (2000), Marcum et al. (1995), McElroy (1989), Menon et al. (1994), Mizuno and Akao (1994), Moran (1994), Moran (1996), Moran (1997), Orth (2000), Peck (1995), Pegels (1995), Pennucci (1989), Rao et al. (1996), Raynor (1994), ReVelle et al. (1995), ReVelle et al. (1998), Rosenau and Moran (1993), Ryan (1988), Sampson and Showalter (2000), Shillito (1994), Shores (1994), Starbek and Kusar (1997), Swift (1995), Swift et al. (1998), Vanegas and Labib (2001b), Wright and Swain (1995), Zhang (2000).

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