SIX SIGMA

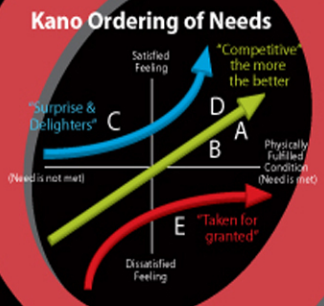
"Joe Ficalora has done an excellent job of updating Cohen's classic text on Quality Function Deployment to show how Six Sigma tools can be effectively used in applying the QFD methodology and how valuable QFD can be in Design for Six Sigma projects. I highly recommended it to practitioners of both disciplines. They will be well rewarded by using this book to guide them in delighting their customers."

—**John L. Schoonover**, Director of Quality, Global Tungsten and Powders

Quality Function Deployment and SIX SIGMA

A QFD Handbook

Second Edition



Foreword by Stephen A. Zinkgraf

JOSEPH P. FICALORA • LOUIS COHEN

Praise for *Quality Function Deployment and Six Sigma*

"Joe Ficalora has done an excellent job of updating Cohen's classic text on Quality Function Deployment to show how Six Sigma tools can be effectively used in applying the QFD methodology and how valuable QFD can be in Design for Six Sigma projects. I highly recommended it to practitioners of both disciplines. They will be well rewarded by using this book to guide them in delighting their customers."

—John L. Schoonover
Director of Quality
Global Tungsten and Powders

Improving a Classic

"For good reasons, the saying 'Don't mess with success' applies to many things in life; thus Lou Cohen and Joe Ficalora have accomplished a feat often fraught with risk. The original book on QFD, by Lou Cohen, was excellent, with ideas and detailed examples for applying QFD to many types of problems. The new edition builds on the original by integrating material on Design for Six Sigma, making it highly likely that it will remain a key reference. Whether you are working on developing a new product or a transactional business process, this updated edition will help you focus your efforts on what customers really want and need—so important to delivering something customers will pay for."

—John P. King
Jewett & King Associates

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Quality Function Deployment and Six Sigma

SECOND EDITION

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Quality Function Deployment and Six Sigma

A QFD Handbook

Second Edition

Joseph P. Ficalora

Louis Cohen

Pearson

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This book is dedicated to my wife Lynn and our children Anne, Katherine, and Mark for their understanding and patience while I was doing late-night edits and early morning re-writes over coffee when I should have been spending time with all of you. Without you, my life would have little meaning, so thank you for all your love and support.

—JPF

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Contents

Foreword

One of the byproducts of the old Total Quality Management ideology was the term Voice of the Customer (VOC). While this term became ubiquitous in the marketing and product-development worlds, it was a relatively empty term because there was no clear methodology defining the Voice of the Customer, nor any roadmap to obtaining valid information about customer wants and needs. That is, until Lou Cohen's first edition of this book.

Before then, VOC was overstated and not well understood. The mantra was, "We've got to get the Voice of the Customer." Everyone in the room would simultaneously nod their heads and readily agree. Then someone would wander up to marketing to get the VOC.

What resulted was the VOC that marketing thought represented the new market. It usually didn't. This phenomenon is readily apparent in the U.S. automotive industry. The major car companies are now in trouble largely because they completely missed the real VOC, which, by the way, the Japanese car companies nailed.

Lou Cohen's first edition of this book put Quality Function Deployment (QFD) on the map as an important method and, more importantly, as a useful tool by which VOC could be clearly defined as information upon which action could be readily taken.

So, why does there need to be a second edition of a fine original? Well, there's more to defining VOC than just QFD. QFD became fairly commonly used among design teams. While at AlliedSignal in the early 1990s, I worked with a team that was developing an innovative new application. The developers showed me their completed QFD with pride and announced, "We have the Voice of the Customer." When I asked how much of the QFD input was derived from actually talking to the prospective customers (mostly from Japan), I was met with blank stares.

The final result: The developer completely missed a new emerging market, because when they actually talked with customers, they found that the customer requirements they *thought* were real in fact weren't. There are a lot of things that need to happen before and after the QFD to create effective results.

Joe Ficalora has been able to integrate QFD with product design. He did this by first mastering Design for Six Sigma (DFSS), which includes QFD. The wonder of combining QFD and DFSS emerges when QFD tells designers what they need to accomplish and DFSS provides the tools by which new designs are executed to create a product that can actually be manufactured.

Joe has done an incredible job of (1) making QFD even more accessible, and (2) linking QFD to Six Sigma and DFSS. I was first exposed to QFD while at Motorola in the late 1980s. I found in my own use of QFD that I had to start with simple 2×2 matrices and graduate to the more complex House of Quality. If this second edition had been available in the late 1980s, I believe my evolution in QFD would have been light-years faster. Use this book as written and you will see immediate improvement in your product development design targets. And, of course, that will lead to growth, which is a good thing!

—Dr. Steve Zinkgraf
CEO, Sigma Breakthrough Technologies, Inc.

Preface

Over the last 40 years, companies in the United States have moved toward new styles of doing business in the face of overseas competitive pressures, the needs of global economics, and the ever-accelerating pace of new technologies. U.S. companies have taken many steps to become more competitive. Early on came the adoption of the Total Quality Management (TQM) approach or one of its many aliases, all of which have stressed customer-driven planning, continuous improvement, and employee empowerment.

A key component of TQM was the adoption of "tools" to assist in creative thinking and problem solving. These were not physical tools, such as computers or micrometers; rather, they were *methods* that relate ideas to ideas, ideas to data, and data to data; that encourage team members to communicate more effectively with each other; and that helped teams to effectively formulate business problems and their solutions.

Quality Function Deployment (QFD) was an adaptation of some of the TQM tools. In Japan in the late 1960s, QFD was invented to support the product-design process (for designing large ships, in fact). As QFD itself evolved, it became clear to QFD practitioners that it could be used to support service development as well.

Today, its application goes beyond product and service design, although those activities comprise most applications of QFD. QFD has been extended to apply to any planning process where a team has decided to systematically prioritize possible responses to a given set of objectives. The objectives are called the Whats,[1] and the responses are

1. Credit is generally given to Harold Ross (General Motors) and Bill Eureka (American Supplier Institute) for the What/How terminology, which is now widely used by QFD practitioners in the U.S.

called the Hows. QFD provides a method for evaluating How a team can best accomplish the Whats.

The basic problems of product design are universal: Customers have needs that relate to using products; the needs must be addressed by designers who have to make hundreds or thousands of technical decisions; and there are never enough people, time, and dollars to put everything that could be imagined into a product or service.

These problems confront the developers of automobiles, cameras, hot-line service centers, school curricula, and even software. QFD can be used to help development teams decide how best to meet customer needs with available resources, regardless of the technology underlying the product or service.

Customers have their own language for expressing their needs. Each development team has *its* own language for expressing its technology and its decisions. The development team must make a translation between the customer's language and its technical language. QFD is a tool that helps teams systematically map out the relationships between the two languages.

The QFD experience has been generally glossed over, as if the process can run itself. Nothing could be further from the truth! Many QFD horror stories have at their root the uninformed decisions of an inexperienced QFD facilitator. The possibilities for wasting time and leading a team into a cul-de-sac are endless.

On the other hand, many QFD success stories have at their root the creative decisions of a capable QFD facilitator. The opportunities for helping teams save time and arrive at breakthroughs are abundant.

Who Should Read This Book

This second edition is meant to bridge the gap between traditional Quality Function Deployment (QFD) and the rise of Lean Six Sigma over the 15 years since the first edition was written. This book is written as a QFD reference for the many Black Belts and Green Belts in Six Sigma and Design for Six Sigma (DFSS).[2] It also fulfills a need for the many engineers, managers, and engineering supervisors who wish to improve their companies' new-product development processes by including QFD, by itself or with deployment of Lean Six Sigma or DFSS. The original great work by Lou Cohen has been retained for the most part, and I have updated it to include some of the key tools, approaches, linkages and methodologies of Six Sigma, including DFSS.

2. The author's blog on DFSS can be useful if you have not read about this before: See www.dfss4u.com. Also recommended is the SBTI Web site's page on DFSS: www.sbtionline.com/OurServices/GrowthExcellence/DFSS.php.

For the novice, it might be worthwhile to read the last chapter first, as it contains a case study involving both QFD and elements of DFSS. That example is one I am intimately familiar with, for it represents my first venture into energy alternatives, namely solar power. For those versed in the QFD side of the methodologies, this second edition presents some of the links to Six Sigma and DFSS. For Six Sigma and DFSS practitioners, this second edition will help show how QFD should be put to use in your projects and tool sequences.

My Experience with QFD, Product Development, and DFSS

I first came across QFD as a methodology in the late 1980s, during my design and development efforts while at AlliedSignal, now Honeywell Corporation. At that time, I had over 10 years' engineering experience and was an optical designer leading a design team for a new family of products. QFD was introduced and taught to us. The matrix approach seemed like a great way to keep track of the multitude of requirements and relationships that drive design decisions during the course of product development. However, when it was introduced, we were taught that Marketing could fill out the customer needs and weight them as to importance. It became obvious to me that such a course of action could possibly get us off-track from the outset of the design and development efforts. In those days, most engineering personnel were not allowed to travel with the Marketing folks to the customers and find out first-hand what customers wanted or needed. I was fortunate to work in an organization that was not so limited in its thinking. At AlliedSignal, Dr. David Zomick, the late William J. Mitchell, and Ernest Lademann created an atmosphere of cooperation between Engineering and Marketing wherein engineers could travel with marketing personnel to customer locations. I learned a lot from these three men about how to link customer needs to design decisions. QFD then helped me personally to understand how to strengthen and document the linkages between customers needs and design decisions; we ultimately created a new product family that flourished and grew in size, employing many people.

When I left corporate employment for management consulting in 1998, I found many of the tools from Six Sigma being deployed into engineering and development activities. At some point, people began calling this Design for Six Sigma. When Sigma Breakthrough Technologies, Inc. (SBTI) created its DFSS program in 1997, QFD was a key part of the comprehensive approach. It has remained so ever since. I have been the product-line owner for our extensive DFSS offerings and customizations for the last few years. In each customized deployment of DFSS, QFD has been retained due to its inherent value in product and service development. I have enjoyed seeing how clients apply the QFD aspect of DFSS to their design and development efforts, and witnessing the many valuable outcomes.

The chance to add to the fine first-edition QFD book that Lou Cohen had written was one I did not wish to pass up. Lou's book highlighted many of the practical how-tos that were missing for me when I was first introduced to QFD as a product-design engineer. The QFD Handbook portion of this book focuses on the *doing* of QFD. This book also addresses other aspects of QFD as well: Parts of this text explain what QFD is, and how QFD can fit in with other organizational activities.

The QFD Handbook section is fairly unique in that it provides detailed information on how QFD can successfully be implemented, along with a wide range of choices for customizing QFD, with their advantages and disadvantages. My original goal for this work was to make the QFD implementation path easier and more accessible to practitioners. If this text continues to serve that purpose, then QFD will be used more widely in the United States, and we can hope for better products, better services, and greater market share as a result.

How to Read This Book

This book is divided into five parts. Each part looks at QFD from a different perspective.

Part I, About QFD and Six Sigma, provides motivation for QFD and puts it into perspective within the framework of the global business environment. It gives the briefest of overviews of what QFD is. It's equivalent to the type of fifteen-minute management summary often given to describe QFD. Read this part if you are new to QFD, or if you would like to find out where it came from and how it has become so well known among product developers.

Part II, QFD at Ground Level, explains QFD in an expository fashion. It's a kind of textbook within a textbook. It explains each portion of the House of Quality (HOQ) in considerable detail. I hope it will be a useful reference for QFD implementers who are looking for detailed information about the HOQ. Read this part if you would like to be fully informed about the House of Quality.

Part III, QFD from 10,000 Feet, assumes the reader has some familiarity with QFD. It provides an organizational perspective on the way product and service development occurs. It shows how QFD can help organizations become more competitive by developing better products and services. Chapter 13 paints a picture of the way the world ought to be, and Chapter 14 discusses the world the way you may have experienced it. If you want to introduce QFD into an organization, you'll find the ideas in Part III to be helpful for developing your strategy for organizational change.

Part IV, QFD Handbook, is where the rubber meets the road. It assumes you have decided to implement QFD, and it shows you how to start, what to anticipate, and how to finish successfully. Part IV assembles the accumulated lessons from the authors' mistakes and from those of many of our colleagues. Read this section before you try to implement QFD. We think it will be a good investment of your time.

Part V, Beyond the House of Quality, points the way to extensions of the HOQ that can take the development team all the way to the completion of its project. Although it is used predominantly for product planning, QFD has the potential to help the development team deploy the VOC into every phase of development. Part V describes some of the possible paths teams can take after completing the HOQ. It also includes some topics that may be of interest to only some readers. These include specialized adaptations of QFD for software and service development, as well as for organizational planning. Read this part if you are comfortable with QFD concepts and are ready to make QFD a key part of your development process. This section ends with a solar energy case study showcasing one of the many ways to integrate the VOC, QFD, and DFSS.

Acknowledgments

This book would not have been possible without the help and guidance of a great many people. First thanks go to Lou Cohen for writing a great first edition and allowing me to modify his excellent work. I thank Dr. Stephen Zinkgraf, whose generosity in all things allowed for my participation on this project. Mr. Dan Kutz was instrumental in keeping things running smoothly at SBTI while I was preoccupied with this book. The same may be said of the entire executive team at SBTI—Ian Wedgwood, Joe Costello, Debby Sollenberger, Dick Scott, our departed friend Mike Brennan, Jesse Ferguson, and Roger Hinckley—who provided invaluable support while I was writing.

To the contributors to and reviewers of this second edition, a great debt is owed for invaluable additions, comments, critiques, and many great discussions. I consider Joe Kasabula as "Mr. VOC" for his lifelong devotion to the art and processes involved therein. I owe Randy Perry a great deal of thanks for his kind words, edits, suggestions, and contributions. For contributions and case examples, I again thank Bill Rodebaugh, Randy Perry, and Roger Hinckley.

I also need to thank God for the life I have led, which in many ways seems so miraculous, looking back. Some would choose to call it luck, but I never have believed that life is just a series of fortunate accidents.

—JPF

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About the Authors

Joe Ficalora is currently the President of Global Services at Sigma Breakthrough Technologies, Inc. (SBTI), a consulting firm for manufacturing, quality, and engineering services, with specialties in Six Sigma and Lean Enterprise applications. In this role, Mr. Ficalora is responsible for the worldwide deployment of SBTI methodologies and for managing the international partners of SBTI.

Mr. Ficalora has more than 20 years of industrial experience in project management, engineering, manufacturing, and quality control. He first came across QFD while at AlliedSignal, now Honeywell, in 1991. His involvement with Quality tools and techniques has been continuous since that time. He designed and developed the highly acclaimed SBTI Six Sigma Master Black Belt Program. He has led Six Sigma deployments in Operations and Engineering at several clients, including Executive and Champion rollout sessions. Mr. Ficalora holds an MEE from Stevens Institute of Technology, and a BS in physics from Rensselaer Polytechnic Institute.

Mr. Ficalora has worked and is certified as a Black Belt and Master Black Belt. He has consulted for clients in the industries of aerospace, medical devices, beverages, health care, and in manufacturing of food packaging, electronics, metal, glass, and plastics. His current interests include DFSS in renewable energy and energy conservation, as well as future energy options, including nuclear fusion. His current interests also include investment performance predictions, economics, crime statistics, and crime prevention within the USA. He has mentored, and designed and taught workshops to Executives, Champions, Master Black Belts, Black Belts, and Green Belts in Design for Six Sigma, Six Sigma in Manufacturing, and Transactional Business projects worldwide. Mr. Ficalora is a top-rated and sought-after instructor and speaker in these areas.

Mr. Ficalora also holds several patents in lasers and optical devices and a patent in process improvement. He is an active member in IEEE and ISSSP.

Lou Cohen was a product developer, computer and software development manager, quality manager, and consultant during 41 years of professional life.

He lived and worked in Japan in 1984, where he extensively studied quality and productivity methods, including a detailed study of the theories of Dr. W. Edwards Deming. Upon his return to the U.S., he became a nationally known expert in the use of Quality Function Deployment. He has helped his clients use QFD in many diverse industries, including electric-power utilities, financial services, medical instruments, software, communications and telecommunications, laundry detergents, aerospace components, and office furniture.

Now in retirement, he lives in Cambridge, Massachusetts.

PART I

About Quality Function Deployment and Six Sigma

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1 What Are QFD and Six Sigma?

This chapter provides an orientation to Quality Function Deployment (QFD) and Six Sigma. It begins with a brief overview of each of these topics. It then provides a chronology of events that led to the current state of QFD and its integration with Six Sigma in the United States. Finally, the chapter discusses some of the ways QFD is being used, independently and together with Six Sigma methodologies today, to provide a sense of the applicability and flexibility of the methods. Current best practices have evolved in the Six Sigma community to include Lean Manufacturing Methods and tools, and therefore is sometimes called Lean Six Sigma or Lean Sigma. For the sake of avoiding certain definition issues, the term Six Sigma will be used for a broad description of the Six Sigma methodologies described herein.

1.1 Brief Capsule Description

1.1.1 Quality Function Deployment Defined

Just what is **Quality**? In English, as an adjective it means "excellent." The original Japanese term for QFD has meanings of features or attributes too. Quality is determined by customer expectations, so you cannot have a quality product or a quality service without identifying your customers and discovering their expectations. The second word, **Function**, means how you will meet customer expectations, or how your products or services will function to meet them. The third word, **Deployment,** defines how you will manage the flow of development efforts to make certain that customer expectations drive the development of your new products and services.

This book provides both formal and informal examples of QFD. In many ways, successful businesses large and small are applying QFD in formal and informal ways. No business can have continued success in the 21st Century without listening and responding to customers. Enabling the reader to learn how to do this better is the fundamental purpose of this book. In the words of W. Edwards Deming: "Learning is not compulsory, but neither is survival."

QFD is a method for structured product or service planning and development that enables a development team to specify clearly the customer's wants and needs, and then evaluate each proposed product or service capability systematically in terms of its impact on meeting those needs. QFD is fundamentally a quality *planning and management* process to drive to the *best possible product and service solutions.* A key benefit of QFD is that it helps product-introduction teams communicate to management what they intend to do, and to show their strategy in the planned steps forward. Management can then review these plans and allocate budget and other resources. QFD helps enable management to evaluate whether the product plans are worth the investment. Working through the QFD process together provides the important benefit of alignment—within the project team, and to management desires.

The QFD process tends to vary from practitioner to practitioner. In all cases, however, successful QFD work requires accurate assessment of customer needs. This begins with gathering the Voices of Customers (VOC), and ends with validating their needs. Some variant of the VOC process is included in most definitions of QFD, Six Sigma, Design for Six Sigma (DFSS), Marketing for Six Sigma (MFSS), Six Sigma Process Design (SSPD), and Technology for Six Sigma (TFSS). An illustration of this front-end work is provided in Figure 1-1.

Clearly, several steps must be followed to determine customer needs before beginning the matrix work that is often associated with the QFD process. QFD is a flawed exercise if it does not acquire well-defined and validated customer voices.

As mentioned above, the QFD process includes constructing one or more matrices (sometimes called **Quality Tables**). The first of these matrices is called the **House of Quality** (HOQ), shown in Figure 1-2. It displays the customer's wants and needs (the VOC) along the left, and the development team's technical response for meeting those wants and needs along the top. The matrix consists of several sections or sub-matrices joined together in various ways, each containing information that is related to the others (see Figure 1-3). As I have often said when teaching various Six Sigma tools, "Some tools flag the gaps, and others fill them." QFD is a method that flags gaps in knowledge, capability, and understanding as the design team works through the various QFD elements. It also keeps track of how key product and process design decisions relate to customer needs.

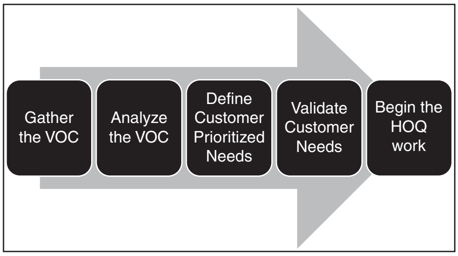

Figure 1-1 Front End of the QFD Process

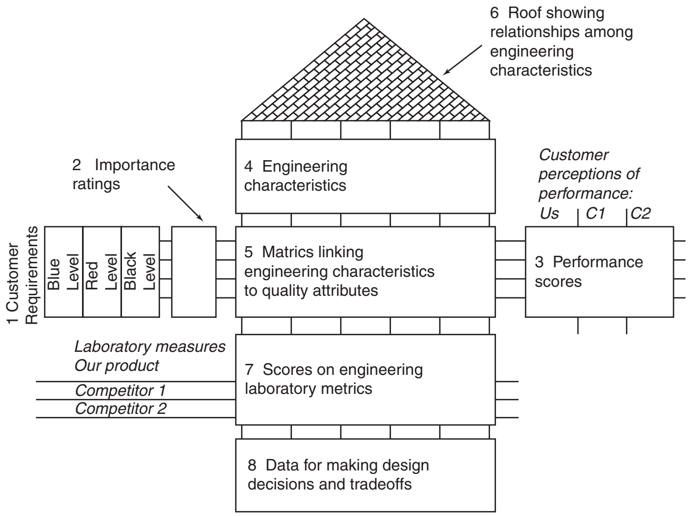

Figure 1-2 The House of Quality

Each of the labeled sections (1 through 8) is a structured, systematic expression of a product- or process-development team's perspective on an aspect of the overall planning process for a new product, service, or process. The numbering suggests one logical sequence for filling in the matrix.

Section 1 contains a structured list of customer wants and needs. The structure is usually determined through qualitative market research. The data is presented in the form of a tree diagram (defined and explained in Chapter 3).

Section 2 contains relative-importance ratings as determined by sampling customers for their priorities.

Section 3 contains two main types of information:

- Quantitative market data, including the customer's satisfaction levels with the organization's and its competition's current offerings
- Strategic goals for the new product or service

Section 4 contains, in the organization's technical language, a high-level description of the product or service it plans to develop. Normally, this technical description is generated from the customer's wants and needs in Section 1.

Section 5 contains the development team's judgments of the strength of the relationship between each element of its technical response and each customer want or need.

Section 6, Technical Correlations, is half of a square matrix, split along its diagonal and rotated 45°. Its resemblance to the roof of a house led to the term House of Quality becoming the standard designation for the entire matrix structure. Section 6 contains the development team's assessments of the implementation interrelationships between elements of the technical characteristics.

Section 7 contains a comparison of product or service metrics between your current offerings and that of competitors.

Section 8 contains relative weighting of customer needs versus how well you are performing on the relevant product and service metrics.

Section 8 contains three types of information:

- The computed rank ordering of the technical responses, based on the rank ordering of customer wants and needs from Section 2 and the relationships in Section 5
- Comparative information on the competition's technical performance
- Technical-performance targets

QFD authorities differ in the terminology they associate with the various parts of the House of Quality. I have tried to be consistent throughout this book, but in day-to-day usage, most people use various terms for sections of the HOQ. I have tried to indicate common alternate terminology whenever I have introduced a new term. There is no reason to be concerned about the lack of standardization; it rarely causes confusion.

Beyond the House of Quality, QFD optionally involves constructing additional matrices to further plan and manage the detailed decisions that must be made throughout the product or service development process. In practice, many development teams don't use these additional matrices. They are missing a lot. The benefits that the House of Quality provides can be just as significant to the development process after the initial planning phase. I urge you to use Part V of this book to become familiar with the later stages of

QFD, and then, with that knowledge available to you, to make an informed decision about how much of QFD your development project needs.

Figure 1-3 illustrates one possible configuration of a collection of interrelated matrices. It also illustrates a standard QFD technique for carrying information from one matrix into another. In Figure 1-3 we start with the HOQ, in this instance labeled 1: Product Planning. We place the Whats on the left of the matrix. Whats is a term often used to denote benefits or objectives we want to achieve. Most commonly, the Whats are the customer needs, the VOC data, but the development team's own objectives could also be represented as Whats. As part of the QFD process, the development team prioritizes the Whats by making a series of judgments based in part on market-research data. Many different techniques for determining these priorities are described later in this book.

Next, the development team generates the Hows and places them along the top of Matrix 1. The Hows are any set of potential responses aimed at achieving the Whats. Most commonly, the Hows are technical measures of performance of the proposed product or service. The relating of the Whats to the Hows is critical, because assumptions can sneak in that are unwarranted. This is why the VOC work preceding the definition of Whats is so crucial!

Based on the weights assigned to the Whats and the amount of impact each How has on achieving each What, the Hows are given priorities or weights, written at the bottom of the HOQ diagram. These weights are a principal result of the HOQ process.

In this simplified view, the second matrix is labeled 2: Product Design. This second matrix could as easily be labeled Service Design; or, if you are developing a complex Product System, it could comprise a sequence of matrices for System Design, Subsystem Design, and finally Component Design. To link the HOQ to Matrix 2, the development team places all, or the most important, of the HOQ Hows on the left of Matrix 2, and the

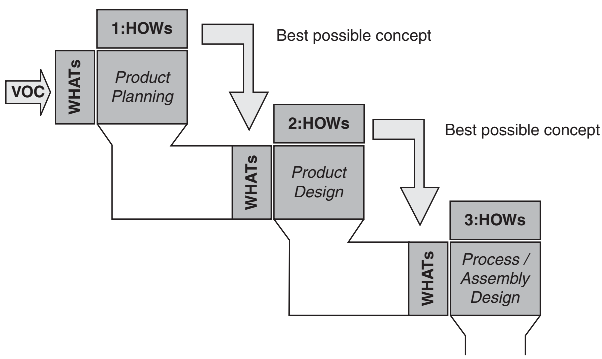

Figure 1-3 Interrelated Matrices

priorities of those Hows on the right. These HOQ Hows now become the Whats of Matrix 2, their relative importance to the development team having been determined in the HOQ process.

To achieve the Matrix 2 Whats, the development team needs a new, more technical or more detailed set of Hows, which are put at the top of Matrix 2. As before, the team uses the weights of the Matrix 2 Whats, and estimates the degree of relationship between the Matrix 2 Hows and the Matrix 2 Whats, to arrive at weights or priorities for the Matrix 2 Hows.

To link Matrix 2 to Matrix 3, the Matrix 2 Hows are transferred to the left of Matrix 3, becoming the Matrix 3 Whats. The weights of the Matrix 2 Hows are transferred to the right side of Matrix 3, and new Matrix 3 Hows are generated.

Each matrix in the chain represents a more-specific or more-technical expression of the product or service. In the classical model for QFD,[1] which was designed for the development of hardware products, the relationship of Whats to Hows in each matrix is as shown in Figure 1-3.

While this model mirrors the process of designing and manufacturing a physical product, similar models exist for developing services, for designing processes, and for developing software products. They are all covered in other parts of this book.

Other multiple-matrix QFD schemes are considerably more elaborate than the three-matrix scheme illustrated in Figure 1-3.[2] Some QFD schemes involve as many as thirty matrices that use the VOC's priorities to plan multiple levels of Design Detail, Quality Improvement Plans, Process Planning, Manufacturing Equipment Planning, and various Value Engineering plans. Some QFD experts believe that the use of additional matrices is not optional, and that the process should not be called QFD unless a series of matrices is constructed. In this book, however, we take a more liberal view; each team must make decisions on how far to go, considering the costs of function deployment versus the value delivered. We take the position that QFD delivers many possible benefits at many levels, and should be implemented at a level of detail appropriate to the task at hand.

Depending on the benefits a development team needs or is willing to work for, it will construct just the initial House of Quality, a large collection of interrelated matrices, or something in between. Teams will further customize their matrices to solve the problems they need to solve. From our point of view, it's all QFD. Adapting the old adage "science is what scientists do," we believe that "QFD is what QFD practitioners do."

1. Don Clausing, *Total Quality Development* (New York: ASME Press, 1994).

2. Bob King, *Better Designs in Half the Time: Implementing QFD Quality Function Deployment in America* (Methuen, Massachusetts: GOAL/QPC, 1987).

Matrix	What	How
House of Quality	Voice of the Customer	Technical Performance Measures
Subsystem Design Matrix	Technical Performance Measures	Piece-Part Characteristics
Piece-Part Design Matrix	Piece-Part Characteristics	Process Parameters
Process Design Matrix	Process Parameters	Production Operations

Figure 1-4 Classical Model for QFD Matrices

As we see in Figure 1-4, QFD is a tool that enables us to develop project priorities at various levels in the development process, given a set of priorities at the highest level (customer needs). QFD is not only a prioritization tool; it is also a **deployment tool.** What we mean by "deployment" is that QFD helps us to start with the highest level of Whats, generally the Voice of the Customer, and to deploy, or translate, that voice into a new language that opens the way for appropriate action. Every developer is familiar with this translation process and probably performs the translation informally all the time. QFD helps make the translation process explicit and systematic.

Finally, QFD provides a repository for product planning information. The repository is based on the structure of the QFD matrices. The matrices allow for entering the Voice of the Customer (and, in subsequent matrices, other deployed What and How information) and all related quantitative information, the Voice of the Developer and all related quantitative information, and the relationships between these voices. This information represents a succinct summary of the key product planning data. To be sure, very detailed elaboration of this information cannot fit in the QFD matrices and must be stored elsewhere. Documenting the matrices provides a golden thread throughout the design process, tracing the design decisions and tradeoffs and potential alternatives for enhanced offerings. The matrices can be viewed as a top-level view or directory to all the rest of the information. In fact, QFD has sometimes been described as a "visible memory of the corporation."[3]

There are many other views of QFD, and many will be explored elsewhere in this book. For now, it will be useful to keep in mind these main ideas: QFD provides a formal linkage between objectives (What) and response (How); it assists developers in developing or deploying the Hows based on the Whats; it provides a systematic method of setting priorities; and it provides a convenient repository of the information.

3. Quote attributed to Max Jurosek, Ford Motor Company, in *Enhanced Quality Function Deployment* (Cambridge, Mass.: MIT Center for Advanced Engineering Study, n.d.). Series of five instructional videotapes.

1.2 What Is Six Sigma?

If you are familiar with this term and methodology, you may want to skip this section. Readers new to this business strategy—and it is a business process—will want to read this section carefully, keeping in mind that it is only an introduction.

Six Sigma can be read about and still greatly misunderstood. In 2006, a shareholder of Honeywell proposed an item to be voted upon at the annual shareholder meeting that Honeywell drop a related use of the term as misleading stockholders and the general public. There are many detailed and descriptive texts on the subject so we will attempt to be brief here, mostly for the benefit of any readers who are new to these topics. I will attempt to describe Six Sigma in terms of its three most widely applied and published interpretations, namely as a metric, a project methodology, and finally as a company initiative.

1.2.1 Six Sigma: The Metric

We will describe Six Sigma as a metric in a very brief manner here, as other sources contain more-detailed descriptions.[4,5] When Six Sigma was developed at Motorola in the 1980s, products were measured in terms of quality by counting their defects. For brevity's sake, we will define a defect for our purposes as anything not meeting customer expectations or requirements. Suppose for example that a customer requires on-time deliveries, specified as "no sooner than two days before promise date nor later than 1 day after promise date." Any delivery made to that customer outside of that range is unacceptable, considered to have a **delivery defect.** Other examples include **packing defects**, such as missing or incorrect items; **shipping defects**, such as arrival with damage or missing paperwork; and, of course, **product defects** in performance or appearance. All defects should be counted if they create customer dissatisfaction or add cost to the business for inspection and correction. However, not all defects are equal: Some have more impact on customer satisfaction and cost than do others. Sound business prioritization must take precedence over simple defect counting as if all were equal.

The goal of Six Sigma can be stated as simple as: "to define, measure, analyze, improve, and control the sources of variations that create defects in the eyes of customers and the business." The count of defects is a key metric. In fact, Motorola production operations focused for a time almost exclusively on reducing defects by an order of

4. Stephen A. Zinkgraf, *Six Sigma: The First 90 Days* (Upper Saddle River, N.J.: Prentice-Hall, 2006).

5. Ian Wedgwood, *Lean Sigma: A Practitioner's Guide* (Upper Saddle River, N.J.: Prentice-Hall, 2006).

magnitude over a specified period of time. If we declare that any defective item has at least one defect, then we can (loosely) state that the yield of any ongoing process is equal to 1 minus the sum of the defects created in that process:

$$\text{Yield} = 1 - \Sigma(\text{defects})$$

We can also count opportunities to create defects in a process. This might be as simple as counting the number of major steps in the process or as complex as looking in-depth at the number of opportunities for errors, mistakes, and non-conformities in the entire process. Whatever method is used, it is prudent to standardize and not change it. For assembled products, one of the best and simplest methods I have seen is to count the number of components for a product and multiply the total by three. The logic of this method is that each component can (1) be purchased correctly or incorrectly, (2) be assembled correctly or incorrectly, and then (3) perform correctly or incorrectly. Each purchased subassembly counts as only one component.

To normalize across different products and processes, the sigma metric involves counting defects and opportunities for defects, and then calculating a Sigma Value. An interim step is to calculate the **Defects per Million Opportunities** (DPMO) as:

$$\text{DPMO} = \Sigma(\text{defects}) \div \Sigma(\text{opportunities}) \times 10^6$$

We use DPMO to arrive at the Sigma Value. The higher the Sigma Value, the higher the quality. The table in Figure 1-5 equates Yield, equivalent defects per million opportunities or DPMO, and the Sigma Value.

We can see that when yields are in the range of 60 percent to 95 percent, we need few other measures to view improvement. However, as we approach 95 percent, our yield measure becomes fairly insensitive and it makes sense to find a more sensitive metric — hence Motorola's use of defect counting. If we further need to compare across vastly different product and process complexities, it makes sense to normalize by opportunity counts. Ultimately, as there are fewer defects to count, it is more important to move away from counting flaws to continuous-scaled measures of performance that tie well to customer satisfaction and product value.

So how do different products and services compare on Sigma Values? Figure 1-6 illustrates DPMO levels in parts-per-million (PPM) versus the Sigma Value.

How is the Sigma Value calculated? In short, it is the number of standard deviations from the mean of an equivalent normal distribution from a specified limit having the same defect rate as the one reported as DPMO. If we assume a defect occurs when any output is beyond the specification limit, then the odds of a defect at a Sigma Value of 6 are approximately 1 in 1 billion. *However,* defect measurements made in the short term are not entirely correlated with results over the long term. Over time, if left unchecked,

99.99966% Yield → 3.4 DPMO → 6 Sigma
99.9767% Yield → 233 DPMO → 5 Sigma
99.379% Yield → 6210 DPMO → 4 Sigma
93.32% Yield → 66807 DPMO → 3 Sigma
69.1% Yield → 308,537 DPMO → 2 Sigma

Figure 1-5 Yield, DPMO, and Sigma Values

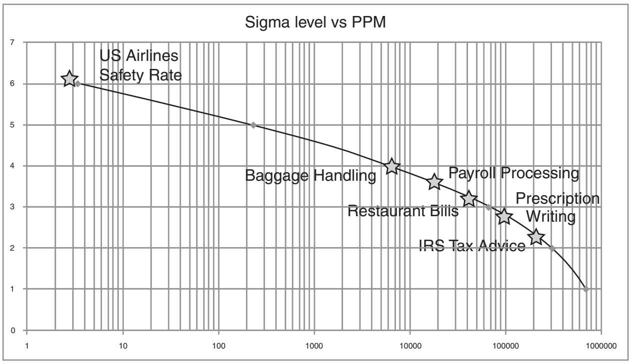

Figure 1-6 Sigma Value versus DPMO, Scaled in PPM

process quality degrades with shifts and drifts in the average output value, inflation of the Sigma Value, or both. A rule of thumb is needed to account for output shifts or degradation over time. Though this is somewhat controversial, George Box has commented that he is glad some accounting for long-term shift is being done.

The rule that is usually applied is that over time, the average change is 1.5 standard deviations. This shift arises originally from work done on tolerance stack-ups and shifts.[6,7,8] The switch to universal acceptance of this amount of shift is often based on empirical experience and not a theoretical construct.[9] I have personally seen long-term shifts of the mean over time between 0 and 4 Sigma, and my best recommendation is to

6. A. Bender, "Benderizing Tolerances—A Simple Practical Probability Method of Handling Tolerances for Limit Stack-Ups," *Graphic Science* (Dec. 1962).

7. H. Evans, "Statistical Tolerancing: The State of Art, Part III: Shifts and Drifts," *Journal of Quality Technology* 7:2 (April 1975): 72.

8. M.J. Harry and R. Stewart, *Six Sigma Mechanical Design Tolerancing* (Scottsdale, Ariz.: Motorola Government Electronics Group, 1988).

9. Davis Bothe, "Statistical Reason for the 1.5 Sigma Shift," *Quality Engineering* 14(3) (2002), 479–487.

aim for 1.5 Sigma. If we reduce our Six Sigma distance by this amount, we get a 4.5 Sigma distance to the upper specification, and the resulting odds of being out of specification rise to 3.4 defects per million items. This is the defect rate number most often touted in Six Sigma quality descriptions. See Figure 1-7 for an illustration of the shift between short-term and long-term performance.

So now we have a Six Sigma metric description, albeit in an oversimplified way for those who are experienced in the craft. This metric can be used in many ways, from counting simple defects to performing simple measurements of product or service output. Knowing these measurements is a key step in delivering quality as measured in the eyes of customers.

1.2.2 SIX SIGMA: THE PROJECT METHODOLOGY

Six Sigma is more than just a metric; it is a project methodology as well. Often QFD is utilized as one of the tools within a Six Sigma project methodology. I view the difference between a tool and a methodology as follows:

- a methodology comprises several steps to achieve an aim or purpose, using multiple tools
- a tool comprises a single function, or multiple functions that may be applied in several ways

When Six Sigma is viewed as a process-improvement methodology, it typically follows a five-phase approach. This approach is sequenced as Define, Measure, Analyze, Improve, and Control (DMAIC). Every Six Sigma process-improvement project follows this sequence, although it may involve taking several loops back, as it is a discovery process in search of causes and controls.

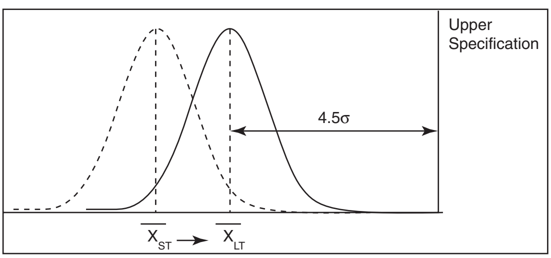

Figure 1-7 The Shift from Short-Term to Long-Term Performance

Six Sigma earns its clout by completing business projects aimed at significant process problems. These problems are identified by an organization in two ways: either top down or bottom up. The bottom-up approach is to listen to customer complaints and/or list internal chronic problems. The top-down approach is to set aggressive business cost-reduction goals and then refine them to a manageable level. Projects are defined around these issues, and all follow the general phases DMAIC. For more on this "project-linked-to-business-goals" approach, see for example *Six Sigma: The First 90 Days* (2006) by Dr. Stephen Zinkgraf.[10]

Within each of the DMAIC phases, key tools are applied to solve the process problems encountered in the project. Project leaders are called either Black Belts or Green Belts in general. Black Belts usually lead the higher-value, higher-risk, higher-visibility, more-complex projects in an organization and receive extensive training in process-improvement tools and statistical analysis, along with some team-building and presentation training depending upon organizational needs. A Black Belt may be deployed in many different areas of the company to solve a process problem. Green Belts typically lead smaller projects, usually within their local areas of expertise, and receive less training. Industry body-of-knowledge standards exist for Black Belt practitioners; and these leaders typically receive four weeks of training spread out over four or five months. Green Belts typically receive nine or ten days of training in two or three sessions spread out over two or three months. Both types of training are excellent for developing your people into more valuable, more versatile company resources.

Much has been written on the tools topic, and an excellent practical text written by my colleague Dr. Ian Wedgwood is called *Lean Sigma: A Practioner's Guide.*[11] This book is very straightforward regarding the tools involved in the methodology.

While consulting at Sylvania in 1998, I was challenged by some excellent engineers to explain how all the tools fit together. I started with a flipchart, and eventually put the major tools into a PowerPoint presentation that many have commented is helpful, so I will repeat it here as a series of figures.

The first step is to begin with the end in mind. We seek potential causes of our primary process issue (Y) and the relationship of the causes to Y. The issues may be multiple but we look at them separately and consider each issue or defect as a process result or Y. This can be stated mathematically as:

10. Zinkgraf, *Six Sigma.*

11. Wedgwood, *Lean Sigma.*

$$Y = f(x_1, x_2, x_3, x_4, \ldots, x_n)$$

Y can be a delivery time, a processing time, a product defect, a service error, an invoicing error or anything that we can explicitly state which can be measured. This Y = f(x) transfer function is the ultimate objective in all good product development work. It is necessary to move forward in QFD as we can associate the Y with Whats and the Xs with Hows. These transfer functions are needed to fill in each QFD matrix. Regarding the equation, some of the tools in the roadmap work on the Y, some help find Xs, and some help establish the relationships to the Y. In the Define and Measure phases we are applying tools at some point that work on Y. These tools are: Measurement System Analysis (MSA), Process Control Charts, and Capability Analysis. MSA helps us determine how much error exists in measuring Y. Control Charts tell us if the Y is stable or predictable, and Capability Analysis helps determine the extent of variation in Y relative to a requirement established during the Define phase. Together these two are called an Initial Capability Assessment. So now our picture looks like Figure 1-8.

The next steps in the Measure and Analyze phases require identifying all the process Xs that are associated with this Y and then funneling them down to the potential few independent variables that truly influence Y. A Process Map is a tool to collect and

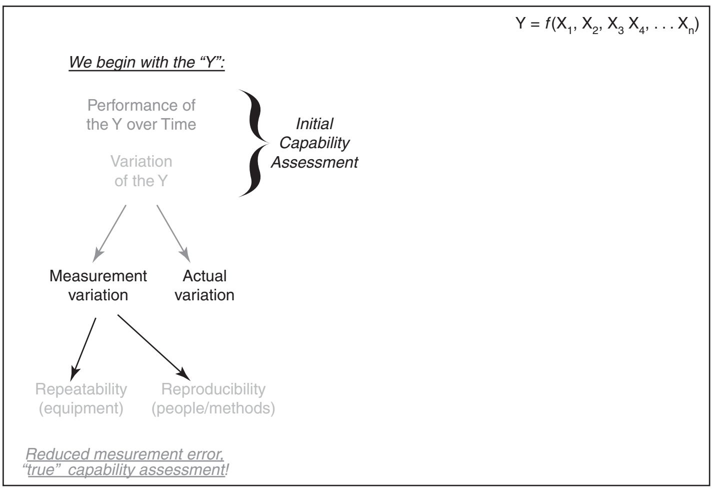

Figure 1-8 Begin with the End in Mind, Y = *f*(x)

identify these Xs, and a variant of a QFD matrix called the Cause and Effect matrix (C&E Matrix) combines the teams knowledge to "funnel" the larger list to known or observed influencers. A Failure Mode and Effects Analysis, or FMEA, helps establish how each independent X variable can be wrong, how severe is its impact, how often it occurs, and whether it can be detected. This helps make some "quick hits" to improving independent potential actors or Xs, and begins stabilizing the process. We now have a smaller number of variables, and we study these Xs passively (Multi-vari) to see if any have statistical correlation with actual variation observed in the Y variable, as shown in Figure 1-9.

In the Improve phase, we take the output of our funnel and begin Design Of Experiments (DOE) to establish true cause and effect relationships of Y = f(x) on our reduced list of suspect independent variables. From there we identify the true actors causing the variability in Y and establish proper controls with a control plan (Figure 1-10).

Now we have the major tools of the Process Improvement Methodology in sequence and relationships to establishing our goal of Y = f(x)!

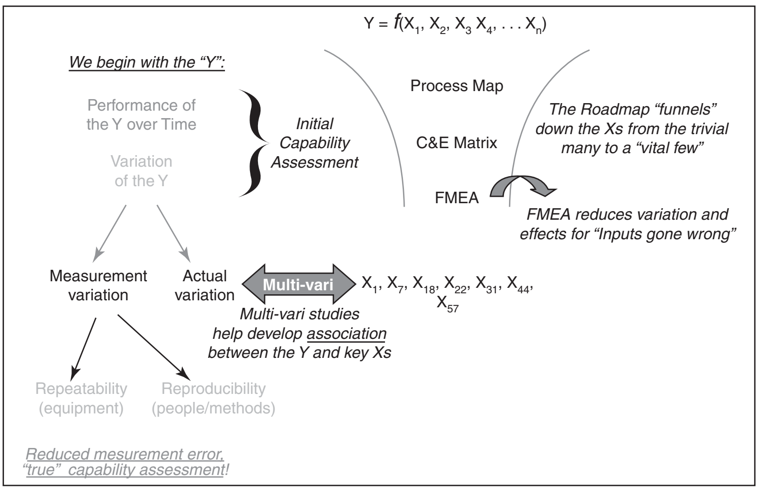

Figure 1-9 Finding and Funneling Down the Independent Variables

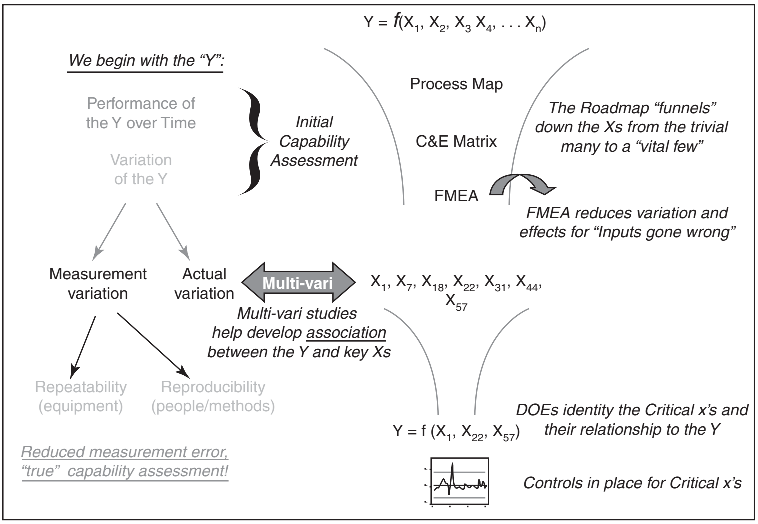

Figure 1-10 Establishing $Y = f(x)$, Finding the Key Xs, and Setting Proper Controls

Six Sigma applied to process problems has as its fundamental aim or goal to define the equation that describes where your desired output gets its dependency: i.e., $Y = f(x)$. So when applying the tools our goal is to develop this key equation. In addition to the Six Sigma Tools, Lean Manufacturing tools were integrated as part of the combining of two separate initiatives while I was at AlliedSignal, now Honeywell, thanks to Larry Bossidy's wisdom on initiatives. There are certainly many ways to combine these initiatives. As a set of tools, it makes sense to combine them with the phased approach of DMAIC. Early on at SBTI, I wrote the DMAIC tools for Six Sigma in the form of the M-A-I-C loop shown in Figure 1-11. We then integrated the Lean tools into these four phases, as seen in Figure 1-12. Following this "Lean Sigma Roadmap" of tools within the DMAIC phases, one can work a project towards a result with less variation in process output, process times, and process flow. Please recall the earlier comments in the methodology introduction that each individual tool may be applied in many ways. This is just one approach to showing how Lean tools and Six Sigma tools may be integrated into a unified methodology of MAIC.

1.2.3 Six Sigma: Deploying as an Initiative

To begin a Six Sigma initiative, top management or executive leaders must create the vision of what the initiative is to do for the company, customers, employees, and owners.

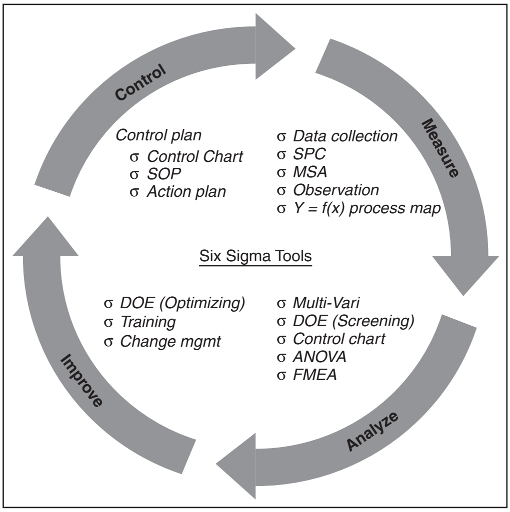

Figure 1-11 Six Sigma Tools in the M-A-I-C Sequence

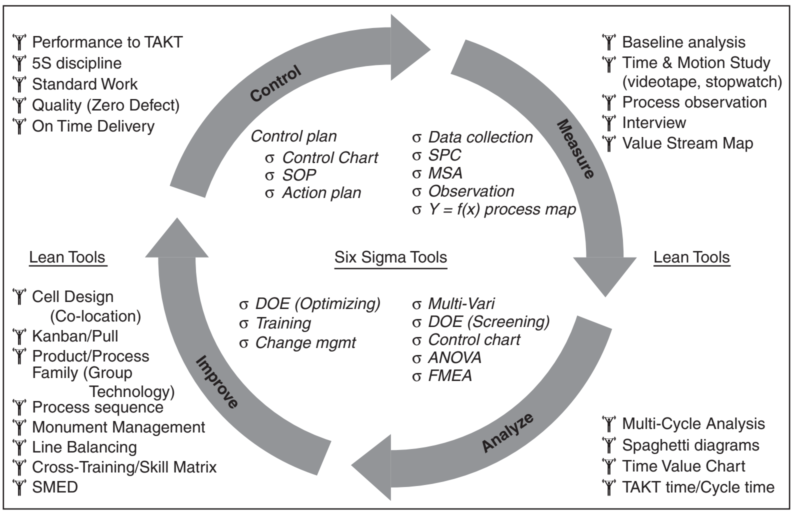

Figure 1-12 Six Sigma and Lean Tools in the M-A-I-C Sequence

They need to foster acceptance with communication, involvement, and leading from the front of the deployment. They must set goals, timing, and financial expectations for the program if it is to be effective. These are often done in off-site meetings or executive workshops. The previously cited work by Zinkgraf[12] provides more depth on these subjects. From these workshops, a deployment plan is developed for the Six Sigma initiative, and it is refined further by champions and sponsors of this effort. The refinement is around people, projects, and training timetables.

Refinement around people and projects means getting the right people on the bus, and then dropping them into the right project areas, armed with the right tools and training. To have great project work on significant business problems, a company needs sponsorship by the business ownership, management, or executive force, or all three depending upon the size of the organization. This requires initiative alignment with strategy, people, processes, business metrics, and customer needs. Alignment with customer needs, strategy, internal stakeholder needs, and business metrics is a great application of QFD and will be discussed further in Chapter 2.

The Black Belts or Green Belts need to know they have support and access to whatever is needed to conduct their project work. It is generally management's job to set expectations and then inspect for progress on tasks, measured against agreed-upon goals. Management must also support and coach the project leaders through the first few projects, and to do so must understand the basics of Six Sigma. People who fill this role in a Six Sigma initiative context are usually described and trained as either Champions or Sponsors. Champions or Sponsors identify the business areas and rough out the projects that are best linked to the business goals and needs. They also identify individuals for training as Green Belts and Black Belts. Green Belts and Black Belts take the projects to training and follow a Plan-Train-Apply-Review cycle through two, three, or four training sessions, depending upon the focus, level, and deployment plan within a company.

Due to the scope of a Six Sigma Initiative and the nature of this book, we will delve no further into the initiative topic. The previously cited work by Zinkgraf[13] will provide more depth in this area.

1.3 History of QFD and Six Sigma

1.3.1 Origins of QFD

The people identified in this chronology have made special efforts in the best interests of U.S. industry. They could have kept QFD and Six Sigma as proprietary secrets, not to be

12. Zinkgraf, *Six Sigma.*

13. Zinkgraf, *Six Sigma.*

shared with the competition. Instead, they shared their experiences with others, including their competitors, and everyone has gained.

QFD became widely known in the United States through the efforts of Don Clausing, of Xerox and later MIT, and Bob King of GOAL/QPC. These two worked independently, and likely first came into contact in October 1985, when Clausing presented QFD at a GOAL/QPC conference in Massachusetts. By that time, both men had already made significant contributions toward promoting QFD.

The Japanese characters for QFD are:

- 品質 (hinshitsu), meaning "quality," "features," "attributes," or "qualities"[14]
- 機能 (kino), meaning "function" or "mechanization"[15]
- 配置 (tenkai), meaning "deployment," "diffusion," "development," or "evolution"

Any of the English words could have been chosen by early translators of Japanese articles. It's little more than a matter of chance that QFD is not called Feature Mechanization Diffusion today. In the early days, when Lou Cohen explained QFD to audiences, he attempted to rename it Structured Planning, or Quality Feature Deployment, in the hope that people would be able to tell from its name what QFD was all about. For better or for worse, "Quality Function Deployment" has stuck in the United States, and no alternative name is likely to survive. None of the thirty-two possible combinations of English equivalents really denotes what QFD actually is. We must be content with a name for the process which is not that self-explanatory.

1.3.2 Early History of QFD in Japan

Yoji Akao[16] cites the rapid growth of the Japanese automobile industry in the 1960s as a driving force behind the development of QFD. With all the new product-development drives in the Japanese auto industry, people there recognized the need for design quality and that existing QC process charts confirmed quality only after manufacturing had begun. Mr. Akao's work with Kiyotaka Oshiumi of Bridgestone led to "Hinshitsu Tenkai" or "Quality Deployment," which was taken to various companies with little public attention. The approach was later modified in 1972 at the Kobe Shipyards of Mitsubishi

14. www.dictionary.reference.com/browse/quality.

15. www.dictionary.reference.com/browse/function.

16. Yoji Akao, "QFD: Past, Present, and Future," paper presented at the International Symposium on QFD (1997).

Heavy Industry to systematically relate customer needs to functions and the quality or substitute quality characteristics. The first book on the topic, *Quality Function Deployment* by Akao and Mizuno, was published by JUSE Press in 1978.[17]

1.3.3 History of QFD in the USA

In 1983, the first article on QFD by Akao appeared in *Quality Progress* by ASQC,[18] and from there things spread quickly. Don Clausing first learned about QFD in March 1984, during a two-week trip to Fuji-Xerox Corporation, a Xerox partner in Japan. Clausing, a Xerox employee at that time, had already become interested in the Robust Design methods of Dr. Genichi Taguchi, who was a consultant to Fuji-Xerox. While in Japan, Clausing met another consultant to Fuji-Xerox, a Dr. Makabe of the Tokyo Institute of Technology.

At an evening meeting, Dr. Makabe briefly showed Clausing a number of his papers on product reliability. "After fifteen minutes," relates Clausing, "Dr. Makabe brushed the papers aside and said, 'Now let me show you something *really* important!' Makabe then explained QFD to me. I saw it as a fundamental tool that could provide cohesion and communication across functions during product development, and I became very excited about it."

In the summer of that same year, Larry Sullivan of Ford Motor Company organized an internal company seminar. Clausing was invited to present QFD. Sullivan quickly grasped the importance of the QFD concept and began promoting it at Ford.

Clausing continued to promote QFD, Taguchi's methods, and Stuart Pugh's concept-selection process at conferences and seminars. When Clausing joined the faculty at MIT, he developed a semester-length graduate course that unified these methods along with other concepts into a system for product development that eventually became called "Total Quality Development." Many of his students, already senior managers and engineers at large U.S. companies, returned to their jobs and spread his concepts to their coworkers.

In June 1987, Bernie Avishai, associate editor of *Harvard Business Review,* asked Don Clausing to write an article on QFD. Clausing felt that the paper should be given a marketing perspective, and he invited John Hauser to coauthor it. Hauser had become intrigued with QFD after learning about it from a visit to Ford. The article, published in

17. Shigeru Mizuno and Yoji Akao, eds., *Quality Function Deployment: A Company-wide Quality Approach* (Tokyo: JUSE Press, 1978).

18. Masao Kogure and Yoji Akao, "Quality Function Deployment and CWQC in Japan," *Quality Progress* 16, no. 10 (1983): 25.