QFD and Design for Six Sigma

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Abstract

In today's fast-paced global economy, time to market constraints are demanding that companies produce their products more quickly and with higher quality. This has driven a shift from inspection based quality where defects are found and repaired, to design based quality where defects are prevented from ever occurring. Through QFD, design of experiments, detailed failure mode analyses, and other quality tools, zero defect or 3ppm defect levels are being achieved by design. This is called Design for Six Sigma (DFSS).

Even greater gains can be made from DFSS when it is combined with QFD to assure not just an absence of defects, but true value as defined by the customer. QFD helps the DFSS team find critical, unmet customer needs and assure they are designed into the product and supported throughout the manufacturing and assembly process. We could call this Customer Driven DFSS. This paper will show how the goals of DFSS can be achieved and surpassed through the complimentary usage of QFD.

Key Words

Six Sigma, DFSS, QFD, Robust Design, FMEA, House of Quality

What is Six Sigma

Since the 1980s, organizations like GOAL/QPC, the American Supplier Institute, and the QFD Institute have brought the leading quality gurus from Japan to teach the U.S. their latest methods such as TQM, 7 QC Tools, 7 Management and Planning Tools, Total Production Maintenance, QFD, Hoshin Planning, Taguchi Methods, Kansei Engineering, and many others. Westerners have been frustrated trying to integrate these tools developed by different people and different schools of thought into a single system.

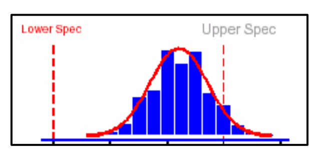

Figure 1a. 3-sigma quality - 66,810 ppm defects

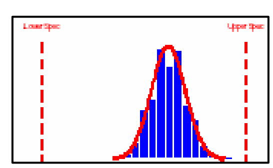

Figure 1b. 6-sigma quality - 3.4 ppm defects

In the late 1990s, General Electric and Motorola began organizing these tools into an improvement process that would assure both customer satisfaction and competitiveness – that is quality that answered to both the top line and the bottom line. Quality was defined by the number of defects or failures in the product, service, or process being analyzed as measured by *sigma*. Sigma is a statistical expression indicating how much variation there is in a product or process. By measuring defective work, improvement targets could be more easily quantified and company wide standards of work quality could be established. Six sigma translates roughly into 3.4 defects per million parts, procedures, lines of software code, etc; and represents a significant improvement over even three sigma (figures 1 a and b). What this means is that the more we can control the variation of a process (human, mechanical, or chemical) so that the natural process limits are within the specification limits, then no matter what degree of controlled variation occurs, the results will be within acceptable tolerances to the customer. Six Sigma is an attempt to apply quality principles and statistical measurement not just to manufacturing processes, but to all corporate endeavors.

These quality principles have been organized into a problem solving algorithm called DMAIC, as shown in Figure 2. Not too dissimilar from the classical Quality Improvement Story's 10-step process, the DMAIC is more measurement oriented and uses more sophisticated tools such as multivariate analyses than does the QI Story. This requires more training, requiring a more defined education and certification process known by its martial arts reference to Six Sigma Champions, Green Belts, Black Belts, and Master Black Belts.

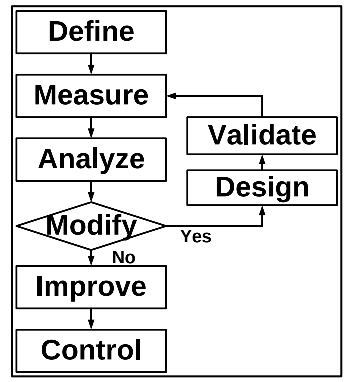

Figure 2 DMAIC

Thus, we can say that Six Sigma brings the following improvements to TQM.

1. Integration of multiple quality tools and systems.
2. Improved process, education, and competence testing with the "belt" programs.
3. Greater use of powerful statistical and analytic tools to measure results.
4. Top line and bottom line accountability to justify improvements both in terms of customer satisfaction and cost-benefit analysis.

What is DFSS

Design for Six Sigma can be seen as a subset of Six Sigma focusing on *preventing* problems, instead of just fixing them. While it shares many of the principles of Six Sigma, DFSS goes further upstream to recognize that decisions made during the design phase profoundly affect the quality and cost of all subsequent activities to build and deliver the product. Early investments of time and effort pay off grandly in getting the product right the first time.

DFSS adds a new, more predictive front end to Six Sigma, replacing DMAIC with IDOV, or Identify, Design, Optimize, and Validate. Details of the IDOV process are given in Table 1.

Table 1. IDOV details – Critical-to-X factors and key measurables.

Phase	CTx	Measurables
Identify	Critical-to-Project Deliverables: Project charter and scope.	Market share, revenue, etc. Resources, budget, schedule.
	Critical-to-Satisfaction Factors.	Customer needs priorities.
	Critical-to-Quality Factors (CTQ)	Prioritized Quality Characteristics and target values and tolerances. y=f(x) transfer function.
	Gaps in the above.	Prioritize Technology, Function, Cost, and Reliability bottlenecks.
Design/Define	Critical-to-Product Factors. Find the source of the gaps and close them.	Key Process Output Variables (KPOV) transferred to Key Process Input Variables (KPIV).
	Design Selection Criteria.	Validate criteria based on controllable and uncontrollable variables (noise), evolve and select best design. Feasibility Study. Vendor selection.
Optimize	Critical-to-Process Tolerances.	Optimize inputs, specify tolerances, conduct sensitivity analysis, and demonstrate process capability and reliability. DOE.
Validate	Critical-to-Production Factors.	Scale-up, Test equipment, Control Plans, Mistake-proof, Standard Operating Procedures, Customer approval. Review and reflect for next project.

DFSS uses the four IDOV phases to identify what measurable and controllable factors are critical to shareholder and customer satisfaction, and then systematically deploys these factors to lower levels of design and build activities. DFSS deploys by clarifying the critical outputs, their targets and acceptable tolerances and then transferring them to controllable inputs, their targets and acceptable tolerances. In this way, the cost implications of holding the tolerances can be mapped to the importance to the customer, and reasonable and acceptable trade-offs can be made.

What is QFD

Quality activities traditionally have focused on improving existing products and processes. For example, statistical process control examines the historical outputs of a process to identify the limits of stable process performance. When the outputs of the process go outside these limits, than we must investigate what has changed to cause this condition. Improvement is then made on the causes of the change. To help identify which causes contribute to the undesirable output, a tool called a cause and effect diagram (figure 3) is used. It is important to remember that while the goal is to improve the undesirable output, actions can only be made on the inputs. With new products, however, processes may not yet be determined.

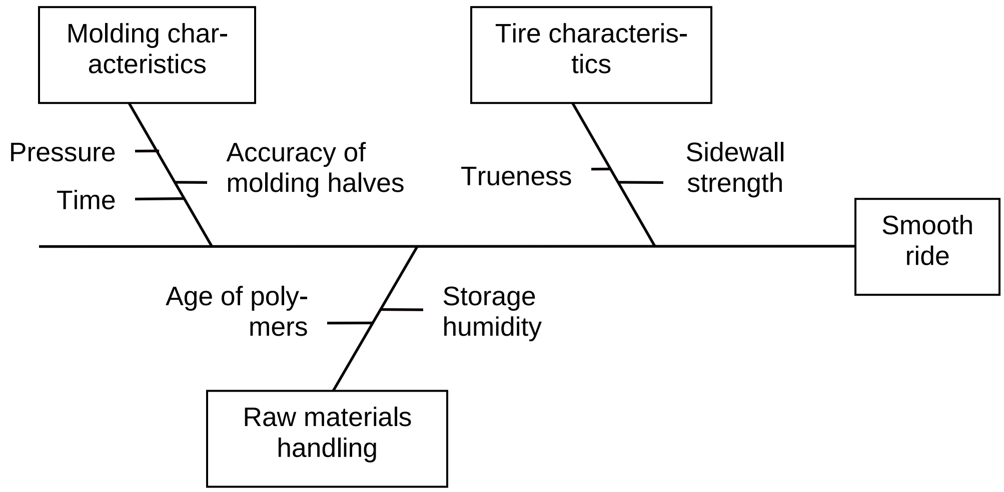

Figure 3. Cause and Effect Diagram as Adapted by Akao for New Products.

To assure the quality of new products, Yoji Akao and Oshiumi adapted the cause and effect diagram in conjunction with a project for Bridgestone Tire of Japan.[1] Instead of identifying the causes of negative quality, he identified the causes of positive quality, that is, those design elements (causes) which could assure customer satisfaction (effects). Thus, if a design team was to deploy their resources where they would yield the largest benefit, they would focus on those design elements which met the following criteria:

1. most important customer segment in terms of business strategy and marketing strategy
2. most important areas of customer satisfaction (needs)
3. which needs do competitors satisfy better
4. there is a strong causal correlation between the needs meeting criteria 1-3 above and the design element
5. the design element has strong causal correlations with multiple important needs.

This elaborate analysis of the cause and effect diagrams grew complicated with large scale projects such as shipbuilding, and were integrated into a spreadsheet by Nishimura of Mitsubishi Heavy Industry Kobe Shipyards[2] in 1972. It's room like appearance caused Sawada of Toyota Auto Body to later refer to it as the "House of Quality."[3] (Figure 4)

The cause and effect relationships can be examined at several levels in the design. For example, customer needs can be fulfilled by product actions or functions. Critical to improve functions or missing functions can be identified by the strength of correlation between the function and the needs. While the cause-and-effect diagram can be used to examine these correlations, the spreadsheet format is more convenient, and so a "house of function" may be created.

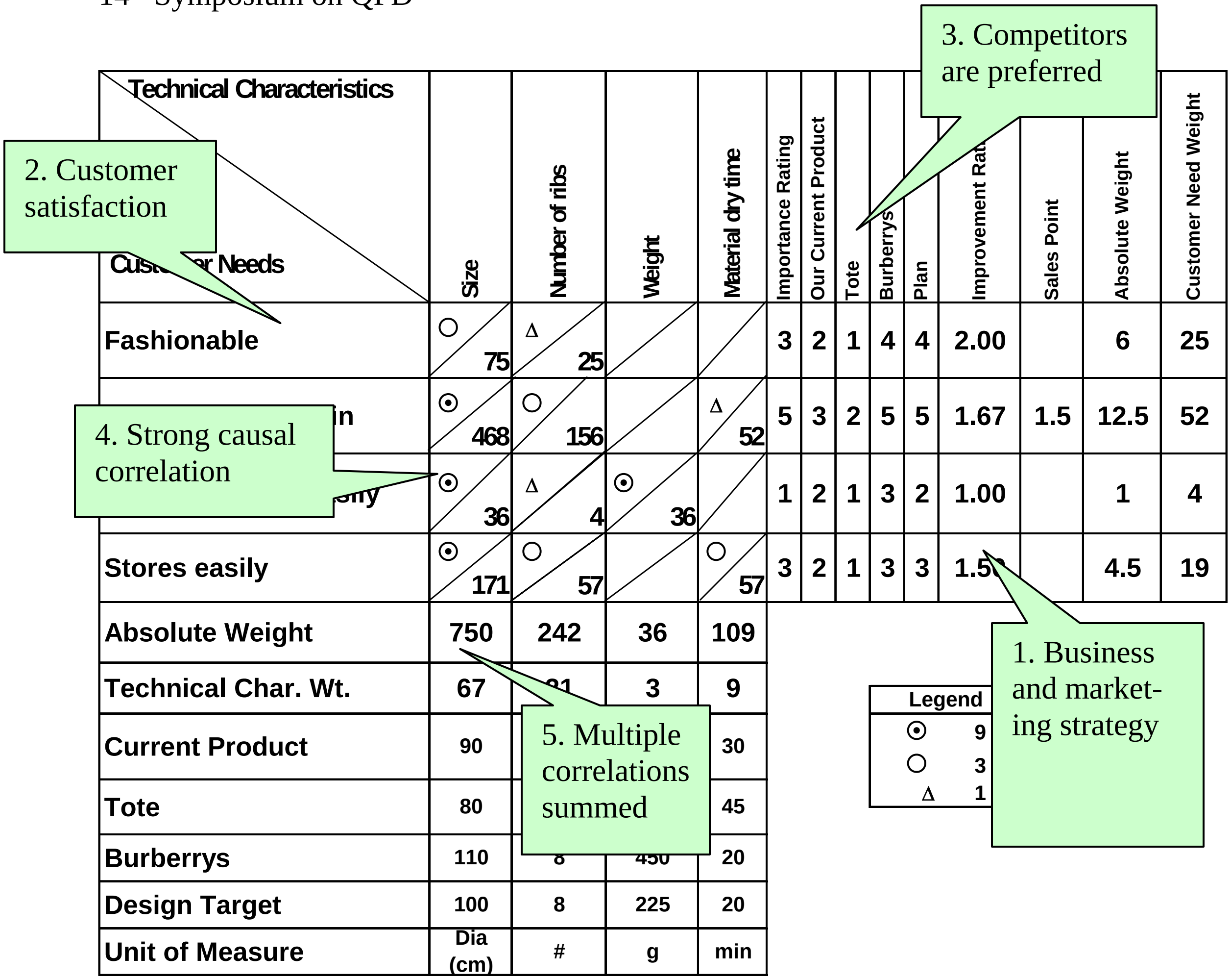

Figure 4. House of Quality for Umbrella

Similarly, potential defects to be avoided in the new design could be prioritized by examining past failure modes, competitor failure modes, warranty claims, etc. and they could be prioritized in a “house of reliability.” Once the design is complete, then the quality of the design must be assured by focusing manufacturing and production activities and facilities on those jobs that have the strongest correlation to changes in the design. This analysis could be depicted in “houses of ‘design for X’.” This model has been easily adapted for service design by the author and others.

QFD and Design for Six Sigma

Section X. of the ASQ’s Six Sigma Black Belt Certification Body of Knowledge is entitled Design for Six Sigma (DFSS). It lists as it subheadings

A. Quality Function Deployment (QFD)
B. Robust design and processes (includes functional requirements)
C. Failure Mode and Effects Analysis
D. Design for X (DFX)

E. Special design tools.

It is easy to see how the QFD model described above fits nicely into ASQ's DFSS model. In fact, it seems as if the designers of the DFSS model were using QFD as a template. Why then, would QFD be listed as section A? It has become common among those whose understanding of QFD is limited to only the House of Quality, to confuse this single use of a cause-and-effect spreadsheet for the entire QFD process. In fact, QFD has not only included sub-sections A-D above, but has been integrated with Taguchi's Robust Design, the Russian ideation model of TRIZ, and other tools, called out in sub-section E Special Design Tools above. A further examination of the entire Six Sigma Body of Knowledge reveals that QFD as originally designed by Akao has relevance to every sections. While QFD is not the only approach needed to master Six Sigma, the author believes that it is one of the most essential.

The one area that QFD can have the greatest impact is in understanding the Voice of the Customer. A weakness of many design teams is that they expect that what the customer asks for is what they want. Numerous studies have shown that what customers ask for is only a starting point for design.

Voice of the Customer Analysis

In a widely cited study by Dr. Noriaki Kano, the existence of both spoken and unspoken needs was highlighted.[4] (Figure 5) Normal Requirements are typically what we get by just asking customers what they want. These requirements satisfy (or dissatisfy) in proportion to their presence (or absence) in the product or service. Fast delivery would be a good example. The faster (or slower) the delivery, the more they like (or dislike) it.

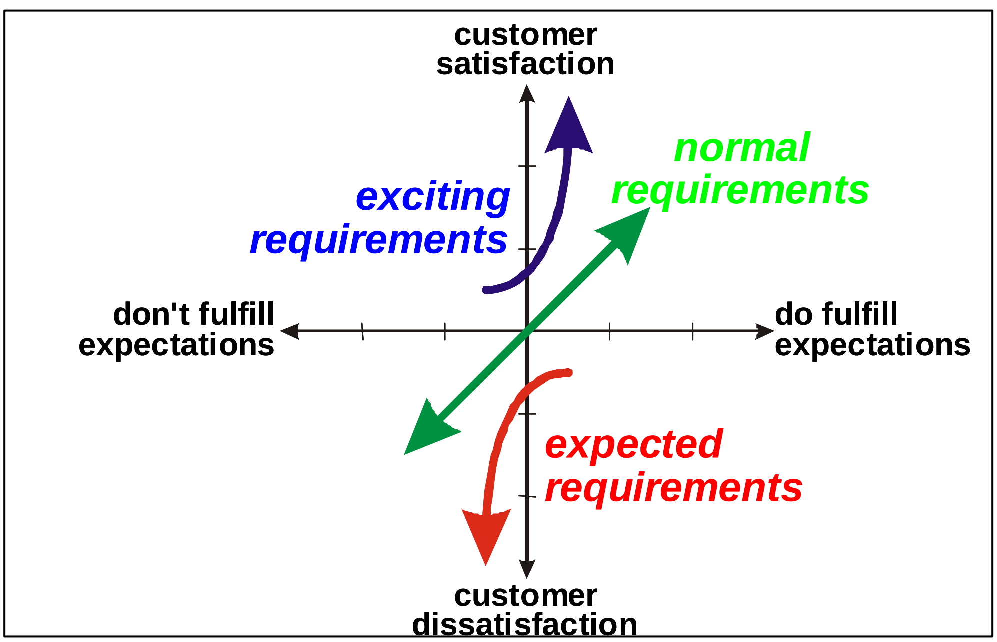

Figure 5. Kano's Model of Quality

Expected Requirements are often so basic the customer may fail to mention them - until we fail to perform them. They are basic expectations without which the product or service may cease to be of value; their absence is very dissatisfying. Further, meeting these requirements often goes unnoticed by most customers. For example, if coffee is served appropriately hot, customers would hardly comment. If it's cold or too hot, dissatisfaction occurs. Expected requirements must be fulfilled.

Exciting Requirements are difficult to discover. They are beyond the customer's expectations. Their absence doesn't dissatisfy; their presence excites. For example, if caviar and champagne were served on a flight from London to Manchester, that would be exciting. If not, customers would not complain. These are the things that wow the customers and bring them back. Since customers are not apt to voice these requirements, it is the responsibility of the organization to explore customer problems and opportunities to uncover such unspoken items. These requirements can shift over time, segment, or other external factors.

If the opportunity to develop differentiated products comes from satisfying unspoken requirements, what should the designers do? After all, they are not mind readers. Despite this difficulty, it has now become the responsibility of the organization to do just that. In a traditional relationship with customers, designers have come to expect the customer to tell them how to do their job – that is, customers dictate through specifications the required performance, dimensions, power requirements, etc. What customers are doing is trying to translate their true needs into language the designers will understand. Experience has shown, however, that even if the design meets the specifications, customers can still be dissatisfied. Wouldn't it be better if the designers could do the translation themselves, and perhaps come up with faster, better, and cheaper specifications? (Figure 6)[5]

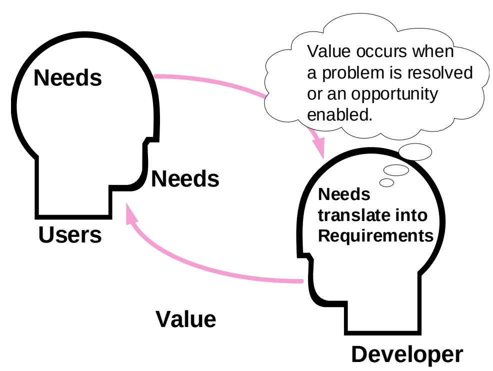

Figure 6. Designers and Developers should "own" the process of translating needs into requirements.

To own the translation of the voice of the customer requires a change in paradigm from caveat emptor (buyer beware) to "caveat vendor" (seller beware). It means more than a passive analysis of specifications, it means a proactive analysis of the customer's behavior *in situ* to better understand their problems, opportunities, and image concerns. It requires that sales, marketing, design, engineering, manufacturing, quality and others form a multi-functional team to visit customers in the process of living their lives and conducting their business. In the context of use, customers will reveal their unspoken needs in the form of smiles or frowns, simplicity or confusion, etc. This is called "going to the *gemba*" in Japanese.

Going to the *Gemba*

This is more than just an observational study in that several tools and methods are employed to systematically examine what the customer is trying to do, and how the product should respond. These tools continue to be refined and augmented by this author[6] and many others.

In fact, the ability of one product to stand out from its competitors may be the results of such a study. For West Bend, observing customers struggling with top-opening bread bakers led to a front-opening design that was deemed "revolutionary" by a trade magazine.[7] For MD Robotics, manufacturers of the NASA Space Shuttle robotic arm and the International Space Station manipulator, it meant visiting the Toronto petting zoo in order to design an animatronic dinosaur for Universal Studios Jurassic Park.[8] This Design Magazine 1999 Gold Medal Winner was more than just a robot, it was, as one paleontologist observed, "alive."

Linking DFSS and QFD

The analytic and process strengths of DFSS are formidable, as are Akao's Comprehensive QFD. Where QFD is stronger is in the upfront analysis of unspoken customer needs. Where DFSS is stronger is the establishment of transfer functions to deploy design parameters downstream, and in establishing cost-benefit analyses and capability studies early in the design phases. Table 2 shows how some of QFD's tools can be added to the IDOV process to strengthen its consideration of unspoken customer needs. QFD steps are indicated in italics. It is obvious that QFD can play a strong role in identifying customer needs, and the House of Quality and other matrices can improve the transfer function process by documenting many-to-many cause-and-effect relationships, their degree of contribution, and controllability.

Further, while DFSS prescribes which tools can be used when for the hard statistical and analytic modeling it does in the DOV phases, it has fewer defined tools and processes for the I phase. QFD is rich in tools to obtain, analyze, and prioritize the Voice of the Customer, so the marriage of the two methods is advantageous to both.

Table 2. QFD added to IDOV.

Phase	CTx	Measurables and Tools
Identify	*Critical-to-Business Factors: Brand, shareholder value, Vision, Mission, Hoshin.*	*Economic value added (EVA) such as ROI, etc.*
	Critical-to-Project Deliverables: Project charter and scope.	Market share, revenue, etc. Resources, budget, schedule.
	Identify Critical-to-Project Customers: Key market segments.	*Market size, influence, price elasticity, ease of servicing, New Lanchester Strategy metrics.*
	Critical-to-Use Scenarios	*Gemba. Frequency of scenario, criticality of scenario, hazards of scenario.*

	Critical-to-Satisfaction Factors.	Customer needs priorities. *Analytic Hierarchy Process. Competitive Benchmarking. Kansei requirements (non-functional).*
	Critical-to-Strategy Factors.	*Product positioning, sales and promotion strategy.*
	Critical-to-Quality Factors (CTQ)	Prioritized Quality Characteristics and target values and tolerances. y=f(x) transfer function. *House of Quality.*
	Gaps in the above.	Prioritize Technology, Function, Cost, and Reliability bottlenecks. *Technology, Function, Cost, and Reliability Deployments.*
Design/ Define	Critical-to-Product Factors. Find the source of the gaps and close them.	Key Process Output Variables (KPOV) transferred to Key Process Input Variables (KPIV).
	Ideation.	*TRIZ: Altshuler's Engineering Parameters, Innovative Situation Questionnaire, Inventive Principles.*
	Design Selection Criteria.	Validate criteria based on controllable and uncontrollable variables (noise), evolve and select best design. Feasibility Study. Vendor selection. *Pugh Concept Selection.*
Optimize	Critical-to-Process Tolerances.	Optimize inputs, specify tolerances, conduct sensitivity analysis, and demonstrate process capability and reliability. DOE. *Parts Deployment.*
Validate	Critical-to-Production Factors.	Scale-up, Test equipment, Control Plans, Mistake-proof, Standard Operating Procedures, Customer approval. Review and reflect for next project. *Process Deployment.*

A WORK IN PROCESS: SEAGATE INTEGRATES QFD AND DFSS

Seagate Technology began its Six Sigma journey over four years ago. Concentrating initially in operational segments of the company, Seagate achieved substantial success. Today, some 600 Black Belts have been trained and over 300 are currently on full time assignment. As a measure of accomplishment, Seagate's Black Belts contributed nearly $800 million in cumulative savings. As a distinct second phase to Six Sigma, Seagate deployed Design for Six Sigma approximately a year later.

In the course of the first year, a single salient feature of Six Sigma became apparent. The application is not a set of tools, or a force for cost reduction, but rather a profound change in corporate culture. Six Sigma will become a game changing way of doing business. DMAIC is a well-documented and structured approach to problem solving, as described earlier.

Choice and applicability drive IDOV selection of tools and methods. For example, tolerances can be developed in several ways with the engineer choosing the best approach. Similarly, transfer functions based on first principles are preferred, but not always available. The engineering team then must choose from other quantitative methods such as design of experiment, regression and correlation techniques.

Initially, Seagate used IDOV as a method for teaching DFSS. While informative, and a useful guide to conceptual application, IDOV lacked the punch needed to drive cultural change. Engineers just didn't get it. Their reaction, so what's new, what do I do differently than before?

Fortunately, two new factors entered the equation: first, systems engineering appeared in the form of DFSS training material from Maurice Berryman, and second new and very different storage markets began to emerge.[9] Systems engineering is not a new concept, but with today's powerful statistical tools and personal computers, the methods are available to every design team. Emerging markets meant Seagate could no longer rely on either existing computer customers or technology to drive new product requirements. A new paradigm was needed.

Quoting Seagate's executive vice president for sales, marketing and customer service, "Seagate traditionally gathered the majority of its market intelligence from the leaders in personal computers and server developers. If I am not doing anything but listening to their opinions, I am going to be lead down the primrose path," he said. "Take something like the MP3 player. Our traditional customers won't tell us anything about the potential usage characteristics of this device. We would be better off visiting college campuses and asking a dozen 19 years old, 'what would you do with this thing?'"[10]

That, in the words of a layman, is a visit to the Gemba. Thus, QFD enters Seagate's front-end process. Because of customer research, Seagate launched into Consumer electronics markets this year and is now a principle supplier to the Xbox from Microsoft. Further, the hard disc drive used in the Xbox is Seagate's first product developed using DFSS methods.

QFD and DFSS are naturally compatible. Developing customer needs and translating them into operational requirements, system performance objectives and specifications that guide design teams seamlessly connect the two concepts into a seamless flow of information.

Seagate has a goal that by 2005, DFSS methods support and enhance all new product developments.

Conclusion

Design for Six Sigma has succeeded in codifying a suggested set of activities to assure customer satisfaction. QFD has provided the tools, methods, and structures to perform those activities, particularly at the critical-to-satisfaction phase. QFD tools, methods, and structures share the same principles as Six Sigma, the principles of TQM and SPC. DFSS specialists are encouraged to expand their capabilities by developing QFD skills. The QFD Institute has been authorized by Yoji Akao to offer several levels of QFD Green Belt^{sm}, QFD Black Belt^{sm}, QFD Master Black Belt^{sm}, and QFD Grandmaster Black Belt^{sm} following a similar designation to that used by Six Sigma specialists. For more details, the QFD Institute can be contacted at qfdi@qfdi.org.

About the Authors

Charles Huber is currently leading implementation of Design for Six Sigma with Seagate Technology, LLP, the world's largest producer of hard disc drives with over 50 million units produced in the last year. Prior to developing DFSS for Seagate, Mr. Huber held senior management positions in engineering and operations with high technology companies such as Digital Equipment Corporation and DataProducts. Mr. Huber received an MBA from the University of St. Thomas in Minneapolis and a Bachelor of Science from Princeton University.

Glenn Mazur, MBA. has been the voice of QFD as Drs. Akao, Mizuno, Ohfuji, and Fukuhara's translator and interpreter since QFD's earliest inception into the United States in the mid-1980s. He is an adjunct faculty teaching TQM at the University of Michigan College of Engineering, Executive Director of the QFD Institute, Executive Director of the International Council for QFD, and president of Japan Business Consultants, Ltd. He is a senior member of the American Society for Quality, Japan Society for Quality Control, and a nominee to the International Academy for Quality. His awards include the 1998 Akao Prize for Excellence in QFD and Certificate of QFD Mastery (QFD Red Belt®) by Akao in 2000. Among his books and publications are Comprehensive QFD for Products, Comprehensive QFD for Services, Comprehensive QFD for Food Products, QFD for Small Business, and Policy Management: Quality Approach to Strategic Planning. Mazur can be reached at **glenn@mazur.net** and **www.mazur.net**.

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