6 History of Taguchi's Quality Engineering in the United States

6.1. Introduction

Genichi Taguchi was born in 1924 in Tokamachi, Niigata prefecture, 120 miles north of Tokyo. His father died when he was 10 years old, leaving him with a hard-working mother, Fusaji, and three younger brothers. Tokamachi has been very famous for centuries for the production of Japanese kimonos. Just about every household had a family business with a weaving machine to produce kimonos. As the oldest boy in the family, Taguchi's intention was to succeed with the family business of kimono production.

Genichi's grandmother, Tomi Kokai, was known for her knowledge of how to raise silkworms to produce the high-quality silk used in kimono production. In the old days in Japan, it was very unusual for a woman to be a well-respected technical consultant. It is interesting that her grandson later became one of the most successful consultants in product development, traveling internationally.

Genichi attended Kiryu Technical College, majoring in textile engineering. However, by the time he returned to his hometown in 1943, the Japanese government had requisitioned all the weaving machines in Tokamachi for use in weapons production, as World War II was to be in progress for two more years. He thus found no family business in which to work.

He was then conscripted into the armed forces and assigned to the astronomical department of the Navy Navigation Institute. As he was charged with tabulating astronavigational data, he encountered and became interested in the *least squares method*, used to estimate a vessel's position from the data available. He then began a self-study of statistics at the Congressional Library in Tokyo.

When, the war ended, the Allied Forces established their general headquarters (GHQ) in Tokyo and set out to help reconstruct Japanese economics and its infrastructure. The U.S. military found that the quality and reliability of the Japanese telecommunication system were very poor. (Some people suggested that it might be better to use smoke signals or carrier pigeons.) GHQ was desperate to improve telecommunications so that they could perform proper intelligence work. GHQ forced the Japanese government to establish the Electrical Communication Laboratory (ECL), on which it spent almost 2% of its national budget. ECL was the first pure research and development organization in Japanese history, modeled after Bell Laboratories in the United States. ECL began operations in 1949 with 1400 people.

ECL and India in the 1950s

After the war, Taguchi joined the Japanese Ministry of Public Health and Welfare, where he worked on collecting data and conducting analysis. While working there, he encountered M. Masuyama of the University of Tokyo, the author whose book on statistics he had studied during the war. Masuyama guided him to develop further his knowledge of statistics and sent Taguchi to industries as a consultant in place of himself. In 1948, Taguchi became a member of the Institute of Statistical Mathematics, part of the Ministry of Education. By the age of 26, Taguchi had, by applying statistical methods, generated numerous successful applications. In 1950, the newly established ECL acquired Taguchi's services. He was assigned to a section responsible to assist design engineers to put together test plans and to conduct data analysis.

For whatever reason, ECL executives decided to compete with Bell Laboratories in developing a cross-bar switching system, which was the state-of-the-art telecommunication system at that time. Table 6.1 compares ECL and Bell Laboratories. In 1957, ECL completed development, meeting all the very difficult requirements, before Bell Labs, and ECL won the contract.

This was the first success story by a Japanese company in product development following World War II. Of course, we cannot conclude that this success was due entirely to Taguchi's ideas. However, during those six years, he developed and applied his industrial *design of experiment*. He developed not only efficient use of such tools as orthogonal arrays and linear graphs, but also developed and applied strategies for product and process optimization, which became the essence of what is today known as *robust design*. Those strategies include:

Table 6.1
ECL and Bell Labs compared

	Budget	No. of People	No. of Years	Result
AT&T Bell Labs	50	5	7	Base
NT&T ECL	1	1	6	Superior

- ❑ Interaction between control factors and noise factors to achieve robustness
- ❑ Inner and outer arrays
- ❑ Two-step optimization
- ❑ A focus on additivity and reproducibility

During development of the cross-bar switching system, ECL had optimized over 2000 design and process parameters. ECL was not a manufacturing company, and its contribution was complete with the design and specifications. Contractors produced the system and subsystems based on the design created by ECL. Then ECL purchased the system from contractors and leased it to users, such as telephone companies and end users. Leases included a 100% warranty for 40 years for the exchanging system and 15 years for telephone sets. In other words, ECL had to repair or replace, at no charge, a failure or defect. Therefore, it was very critical for ECL to assure performance, quality, and reliability at the stage of product design. This is why ECL was forced to think of robustness before aging and the customer's environment.

During the development phase, Taguchi also consulted contractor companies, such as Toshiba, Hitachi, and NEC, to optimize their processes. On weekends, Taguchi continued to consult industries outside telecommunications. A famous study at Ina Seito, a ceramic tile manufacturing company, was conducted in 1953.

In 1955, Taguchi visited the Indian Statistical Institute in Calcutta, India, for almost a full year as a visiting professor in place of Masuyama. In India, he met P. C. Mahalanobis, the founder of ISI, and Shewhart from Bell Labs. After he came back, he published the first edition of a two-volume book, *System of Experimental Design* (Tokyo: Maruzen). In 1962, Taguchi was granted a Ph.D. degree in science from Kyushu University for his work in developing the industrial design of experiments. In 1960 he was awarded the Deming Prize from the Japanese Union of Scientists and Engineers.

Princeton University, Bell Laboratory, and Aoyama Gakuin University

In 1963, Taguchi went to the United States for the first time and spent one year at Princeton University and Bell Labs. He faced a culture shock but fell in love with the American way of life and thinking, especially with its rational, pragmatic, and entrepreneurial spirit. During that time, his work was concentrated in the area of the SN ratio for digital systems.

After he returned from the United States, he was invited by Aoyama Gakuin University to act as a professor in its newly established engineering college. He taught industrial and management engineering for 17 years, until his retirement in 1981. During that time, he lectured at other universities, including the University of Tokyo and Ochanomizu University.

Taguchi leads the Quality Control Research Group (QRG) at CJQCA, the Central Japan Quality Control Association. The organization includes Toyota Motor Company, its group companies, and many others. The group has been meeting monthly since the 1950s. He has led a similar research group at the Japanese Standard Association (JSA) in the Tokyo area since 1961. This group has also been meeting monthly since its start.

While teaching at Aoyama, Taguchi has continued to teach seminars at the Japanese Union of Scientists and Engineers, CJQCA, and JSA and to consult with numerous companies from various industries. He says that he must have consulted on over 150,000 projects over the years. He has written a monthly article for JSA's publication, *Standardization and Quality Control*, for over 40 years. He has authored literally hundreds of articles and published many, many books on his techniques and strategies.

In addition to concepts developed during the ECL era, he has continued to develop new tools and strategies, such as:

- ❑ Quality loss function
- ❑ Parameter design
- ❑ Tolerance design
- ❑ Business data analysis (experimental regression analysis)
- ❑ Dynamic SN ratio for measurement systems
- ❑ SN ratio for digital data
- ❑ On-line quality engineering
- ❑ Management by total results
- ❑ Nondynamic SN ratios
- ❑ More sophisticated two-step optimization
- ❑ Parameter design with computer simulation
- ❑ Dynamic SN ratios

His methodologies were introduced to the United States in the early 1980s and spread throughout U.S. industries. This process can be divided into four periods.

6.2. The Beginning, 1980–1984

It was very much by coincidence that three organizations, Bell, Ford, and Xerox, encountered Taguchi's methodologies within a one-year time frame, around 1981. All three experienced a culture shock, then promoted the methodologies.

Bell Laboratories

In 1980, Taguchi wrote a letter to Bell Labs indicating that he was interested in visiting them while on sabbatical. He visited there on his own expense and lectured on his methodology to those who were involved with design of experiment. These people were interested but still skeptical. They included Madhave Phadke, Rague Kakar, Anne Shoemaker, and Vijayan Nair, who were students of the famous statistician George Box at the University of Wisconsin or of Stu Hunter at Princeton.

Taguchi asked them to bring him the most difficult technical problem that they were facing. They brought the problem of 256k photolithography. The process was to generate over 150,000 windows on a ceramic chip. The window size had to meet a requirement of 3.00 ± 0.25 μm. The process yielded only 33% after several years of research. Taguchi designed an experiment with nine process parameters assigned to an inner array of L_{18} and measured the window size as its response. Noise factors in the outer array were simply positioned between chips on a wafer and within chips. Then the response was treated as a nominal-the-best response and the now famous two-step optimization was applied. The yield was thus improved to an amazing 87%. People at Bell Labs were impressed and asked him to keep it secret for a few years, although the study was published in the May 1983 issue of the *Bell System Technical Journal*. Taguchi continued to visit Bell Labs frequently until its huge reorganization later in the 1980s.

Ford Motor Company

In 1979, Edward Deming was featured in an NBC White Paper 90-minute TV program titled "If Japan Can, Why Can't We?" Deming was introduced as the father of quality in Japan. In 1950, because of his statistical competence, Deming visited Japan to help development of a national census. During his visit, the JUSE had asked Deming to conduct seminars with Japanese top executives. He had preached to Japanese industrial leaders the importance of statistical quality control (SQC) if the Japanese were interested in catching up to Western nations. Because Japanese top executives were good students and had nothing to lose, they practiced what Deming preached. Later, JUSE established the Deming prizes for industries and individuals. Based on his teaching, Japan had developed unique total quality management systems, together with various practical statistical tools, including Taguchi methods.

In the United States, it became apparent in the late 1970s that made-in-Japan automobiles were starting to eat into the market share of the U.S. Big 3, starting with markets in California. U.S. industries were puzzled as to how the Japanese could design and produce such high-quality products at such low cost. Then the TV program featuring Deming was broadcast. Ford's CEO Don Peterson had hired Deming and started Ford's movement called "Quality Is Job #1" under Deming's guidance. Deming suggested that Ford establish the Ford Supplier Institute (FSI) to train and help its suppliers in Deming's philosophy with statistical tools such as Shewhart's process control chart. FSI conducted seminars, and thousands of Ford and supplier people were trained in SPC and Deming's quality management philosophy. Deming also suggested that they send missions to Japan to study what was being practiced there.

During the mission in spring 1982, Ford and supplier executives visited Nippon Denso. They found that Denso's engineering standards, in their thick blue binders, were of very high quality and of a type they had never seen. They asked how such excellent technical knowledge had been developed as part of corporate memory. They mentioned various statistical techniques and emphasized Taguchi's design of experiment for product/process optimization. Taguchi happened to be consulting at Denso that day. The leader of the mission, Larry Sullivan, immediately asked Taguchi to visit Ford and give lectures.

Taguchi visited Ford in October 1982 and gave a five-day seminar with a very small English handout. It was somewhat difficult for both sides because of translation problems, but the power of his ideas was understood by some participants. FSI decided to include Taguchi's design of experiment in their curriculum. Yuin Wu, a long-time associate of Taguchi's, was hired by FSI. Wa translated training material and began to conduct seminars with FSI. Wu, who is from Taiwan, was very knowledgeable in Japanese quality control and its culture, especially in Taguchi's methodologies. He had immigrated to the United States in the mid-1970s and is credited with conducting the very first Taguchi-style optimization study in the United States.

In May 1983, Shin Taguchi, a son of Taguchi's, joined the FSI. Shin is a graduate of the University of Michigan in industrial and operations engineering. Wu, along with Shin and other professors, taught Taguchi's design of experiment (DoE) to Ford suppliers week after week. Then, to qualify as a Q1 Ford supplier, Ford made it mandatory to practice DoE in addition to SPC. Those supplier companies included huge conglomerates such as ITT, GE, United Technology, and GTE. Because of that, Taguchi DoE became well known outside the automotive industry. Willie Moore of Ford claimed that Ford had contributed greatly to promoting Taguchi's DoE in U.S. industries. In 1984, FSI became ASI, the American Supplier Institute, one of its goals being to conduct training and implementation assistance for companies other than Ford and its suppliers. The first Taguchi Symposium was held by FSI in 1984, and it has been held annually since then. The Taguchi symposia contributed greatly to promoting the latest and greatest of Taguchi's methodologies.

Xerox At Xerox Corporation, after its xerography patent had expired, management could not help but notice that many Japanese office imaging companies were shipping small and medium-sized copy machines to the United States which produced high-quality copies at low cost, taking market share from Xerox. They were especially anxious to protect their large-machine market share. They had no choice but to conduct a benchmark study. Xerox had a sister company called Fuji Xerox, owned 50–50 by Rank Xerox of Europe and Fuji Film of Japan. Xerox found out that Fuji Xerox could sell a copy machine at the manufacturing cost to Xerox and still make a handsome profit.

Fuji Xerox was established in the mid-1960s and had no technical know-how regarding copy machines. Yet, after 15 years, Fuji Xerox had developed the technical competence to threaten Xerox Corporation. They found that Fuji Xerox was practicing total quality management and various powerful techniques, such as quality function deployment (QFD) and Taguchi's methodologies for design optimization. Xerox found that Taguchi had been a consultant to Fuji Xerox since its establishment and suspected that Fuji's competence had something to do with implementing Taguchi's methodologies.

Xerox invited Taguchi to visit in 1981, and he began to provide lectures and consultations. Xerox executive Wayland Hicks and his people, including Barry Bebb, Maurice Holmes, and Don Clausing, were to take leadership in implementing QFD and Taguchi methods. Clausing, the creator of the concept of *robustness* called "operating window," gave the method *Taguchi methods* to Taguchi's approach to design optimization. Clausing later became a professor at MIT and taught total product development, in which QFD and Taguchi methods played a major role.

6.3. Second Period: Applications to Quality Problem Solving, 1984–1992

In 1980, there were fewer than 10 consulting companies in the area of quality in North America. By 1990, the number has grown to more than 300. During the 1980s, U.S. industries introduced TQM, policy (Hoshin) management, just-in-time, the Toyota production system, TPM (total productive maintenance), 7 basic tools, 7 management tools, poka yoke, SPC, FMEA, QFD, design of experiment, Taguchi methods, and many others. Many people were calling these endless initiatives "flavors of the month," "alphabet soup," or "the kitchen sink." However, Japanese total quality management was the thing to practice during the 1980s.

During this period, most applications of Taguchi methods focused on *firefighting*, solving *existing* manufacturing quality problems. Naturally, the responses measured were nondynamic, typically smaller-the-better or larger-the-better response. For example, a typical objective was to minimize defects such as voids, shrinkage, cracks, leakage, audible noise, and so on, or to maximize strength, time to failure, pressure to leak, and so on. Two-step optimization with nominal-the-best was mentioned but not emphasized enough, and it was not practiced as much as it should have been. In reality, Taguchi methods in the 1980s in the United States were nothing but fractional factorial design of experiment to solve manufacturing quality problems. Many successful studies were reported, with cost saving in the millions of dollars, and Taguchi methods were becoming more and more popular. When these tremendous cost reductions were reported, typical Japanese practitioners were saying: "Why is so much cost reduction possible? In Japan, that kind of cost reduction is unheard of, because we reduce cost from the beginning." I believe that part of the reason that even simple design of experimentation was not used in typical U.S. corporations is that it was practiced only by statisticians in R&D environments.

The Department of Defense also promoted Taguchi methods in the late 1980s. The U.S. Air Force published the *Reliability and Maintainability 2000 Program* in 1988, which encouraged contractors to practice Taguchi's quality loss function and parameter design.

As soon as the Bell case study on photolithography was published in 1983, Taguchi's approach to industrial design of experiment was recognized by the U.S. statistical community. Since that time, many articles on Taguchi methods have appeared in magazines and journals such as *Quality Progress, Quality, Journal of Quality Technology, Technometrics, Quality Engineering,* and *Quality Observer*. By then, Taguchi methods had caused tremendous debate and controversy. Some people were supportive and very enthusiastic, some were against use of the methods and antagonistic, and others were neutral. The positive responses can be summarized from these articles as follows:

1. The quality loss function and its philosophy are valuable concepts.
2. The methods are useful to analyze and optimize variability.
3. Inner and outer arrays are useful designations.
4. Two-step optimization is a valuable process.
5. Getting engineers to conduct balanced/orthogonal experimentation is a great contribution.
6. DoE tools are easy for engineers to use.
7. This is a wake-up call to the quality movement in U.S. industries.
8. Prediction and confirmation are very consistent with the PDCA cycle.

The following criticisms were made:

1. Taguchi ignores interactions among factors.
2. Taguchi ignores interactions between control factors.
3. The validity of accumulation analysis for attribute data is questionable.

4. The validity of the SN ratio for nominal-the-best response is questionable.
5. The validity of signal-to-noise ratio for smaller-the-better response and larger-the-better response is questionable.
6. There is a lack of statistical testing in parameter design.
7. There is no use of distribution theory.
8. Taguchi does not provide a model.
9. Taguchi does not credit statisticians.
10. Taguchi has made contributions, but there is a better way to do what he is trying to do.

Meanwhile, Taguchi was coming to the United States in May and October every year, visiting Xerox, Ford, ASI, Bell, ITT, General Motors, and many other companies. He made numerous presentations at conferences and symposia. He also visited universities and professional societies. As he visited them, he emphasizing that his method was misused and that he prefered to see it used for design optimization for robustness rather than for quality problem solving. Quality problem solving focuses only on a symptom of poor functioning. It works on a nonoptimized design to solve problems. If the design were optimized, there is a good chance the problem would not have existed. Robust optimization focuses on optimizing the energy transformation of a system to get rid of all symptoms. It is important to recognize that any hardware function is essentially a series of energy transformations and that defects and failures are nothing but symptoms of energy transformation variability.

The idea of energy transformation, its ideal functioning, and the dynamic SN ratio became better understood in the late 1980s. At the 1987 ASI Taguchi Symposium, Taguchi said: "From now on, every case study must use dynamic response based on the ideal function of energy transformation." The theme of the Taguchi Symposium in 1988 was: "To get quality, don't measure quality"; but it was the least well attended symposium. Taguchi methods were very successful, saving millions of dollars by solving problems related to defects and failures, but it was not easy to change the emphasis from firefighting to design optimization—it has taken several years to make this transition.

The first U.S. case study using dynamic response was conducted by Flex Technology and presented at the 1988 Taguchi Symposium. ASI had begun to change its training material from an emphasis on firefighting to one of fire prevention. However, many U.S. industries had just begun their quality movement, and most companies were not ready to digest Taguchi's upstream thinking.

By 1990, an initial quality survey of the number of things that go wrong in the first three months in service reported that Ford cars were as good as many Japanese-made automobiles. It was a 400% improvement over the early 1980s, when typically three things were going wrong per car. It was a great improvement; however, Ford was still having problems in the area of warranty and resale value. It indicated the necessity to improve not only initial quality but also reliability and durability. Ford executives recognized that this was not just a manufacturing problem but that product design engineering had to be involved to develop products that were robust against customers' environments and aging.

6.4. Third Period: Applications to Product/Process Optimization, 1992–2000

By 1992, TQM had become less popular because of its vagueness and its spiritual nature. In place of TQM, *six sigma* was popularized by Mikel Harry, Larry Bossidy (Allied Signal CEO), and Jack Welch (GE CEO). On the other hand, Taguchi methods had evolved from a quality problem-solving tool to a system of robust engineering for fire prevention.

In Japan, the Quality Engineering Society was formed and began to publish a bimonthly technical journal in 1993, its mission being to research and advance applications of Taguchi methods in various industries. Originally simply a forum with 600 members, today it is an official society with a membership of more than 2000. Taguchi was the first chairman, and the chief editor for the technical journal was Hiroshi Yano. The journal has contributed tremendously to accomplishing the society's mission.

Ford Motor Company established the Ford Design Institute in 1992 and began to generate robust design case studies. With FDI, more than 100 projects were completed from 1993 to 1995. In addition to Ford Motor Company, ITT, Kodak, Xerox, Delphi, the Bobcat Division of Ingersoll-Rand, and many other companies were starting to apply robust design in product development, using dynamic response based on energy transformation.

Since Taguchi began to emphasize dynamic response based on energy transformation in the late 1980s, Taguchi methods have advanced further. These new ideas and techniques include:

- SN ratio used in conjunction with operating window response (originated by Xerox's Don Clausing)
- Dynamic SN ratio based on the ideal function of energy transformation
- Dynamic SN ratio in chemical and biochemical systems
- Dynamic SN ratio using complex numbers
- Dynamic SN ratio in software function
- Noise compounding
- New ideas on noise strategies
- Double signal dynamic response
- Triple signal dynamic response
- Dynamic operating window response
- Speed ratio method
- Mahalanobis–Taguchi system for diagnostic/pattern recognition system optimization
- Robust software testing (software debugging using orthogonal array)
- Standard SN ratio for continuous variable

Figure 6.1 summarizes the development of robust engineering in the United States.

The six sigma technique became popular in the mid-1990s. Successful implementation by Jack Welch of General Electric contributed greatly to its popularity. For instance, GE reported a large annual saving in 1998. GE scheduled 50,000 six sigma and design for six sigma (DFSS) projects in 2002.

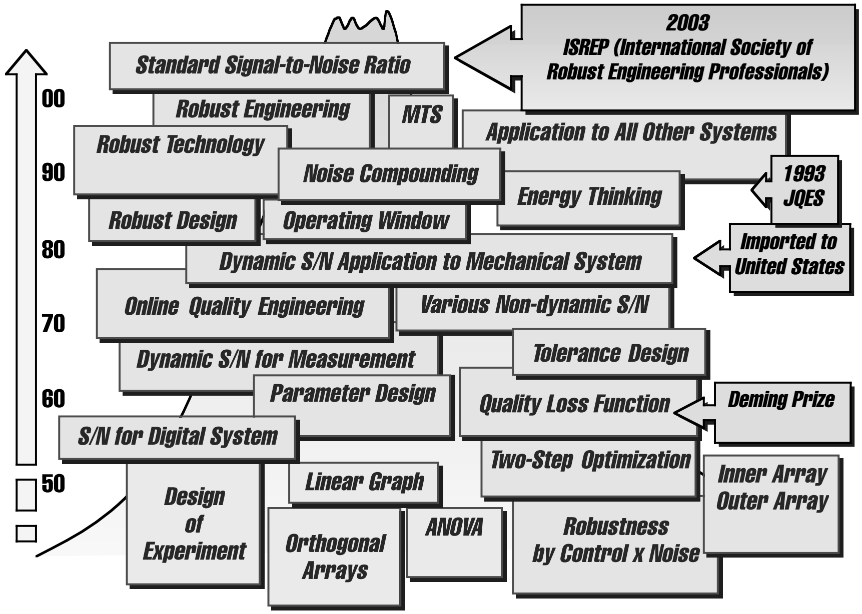

Figure 6.1
Development of robust engineering

While the DMAIC (define–measure–analyze–improve–control) process of six sigma typically deals with solving current problems and reducing waste, DFSS's IDDOV (identify opportunity–define requirement–develop concept–optimize concept–verify and launch) process optimizes design of product and processes to prevent future problems. Robust engineering plays a major role in DFSS, especially at the optimization stage. Corporations such as Delphi, Caterpillar, Hyundai-Kia Motor, TRW, and many others are integrating robust engineering into their DFSS deployment. Figure 6.2 shows the DFSS and RE deployment process, and Figure 6.3 shows the monetary savings expected from DFSS and RE activities. DFSS is an excellent vehicle to use to integrate robust engineering into new product introduction for pure "prevention."

During this period, many excellent studies were developed and presented in Japan, the United States, and Europe. The Quality Engineering Society in Japan hosts an annual symposium in June every year, with over 900 people participating. ASI continues to host an annual Taguchi symposium in October with approximately 200 participants. ITT has its own annual Taguchi symposium, with around 200 people participating. In 1995, ASI started a 16-day Taguchi expert course; more than 360 engineers have graduated at this point.

Taguchi was inducted to the Automotive Hall of Fame in 1997 for his contribution to Big 3's quality improvement. He also received an honorary membership in the ASQ in 1996 and the same honor from ASME in 199X. These awards are evidence of the contributions made by Taguchi methods in U.S. industries.

Additionally, new ideas developed in recent years were published in the late 1990s. *Robust Engineering* by Taguchi, Chowdhury, and Taguchi was published by McGraw-Hill in 2000. *Taguchi Methods for Robust Design* by Wu and Wu was published

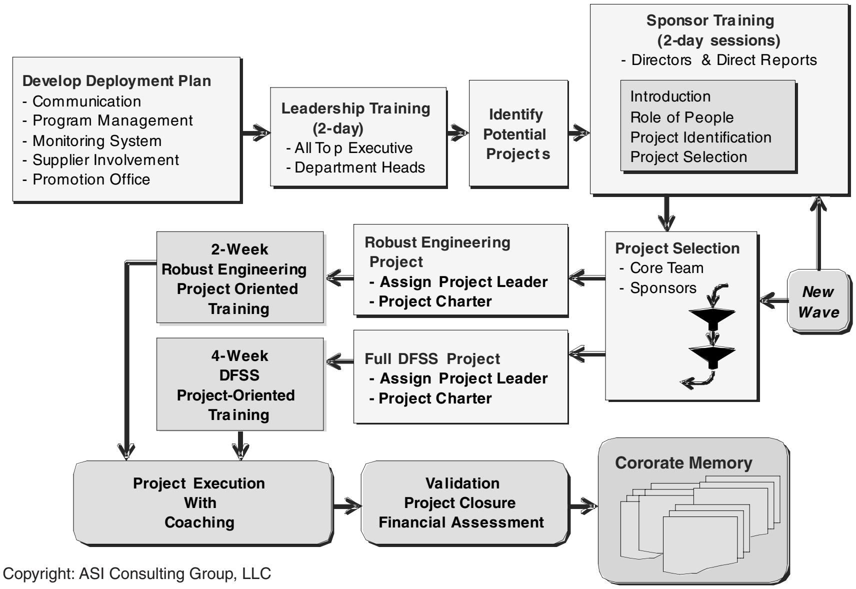

Figure 6.2
DFSS and RE deployment model

by ASME Press in 2000. *Mahalanobis–Taguchi System*, also published by McGraw-Hill, appeared in 2001.

Despite all these publications, there remain many misconceptions regarding Taguchi methods. Most people still take them to be quality problem-solving tools and do not recognize their application to fire prevention. Only those companies trained by ASI seem to be using Taguchi methods for design optimization.

	Robust Engineering	Full DFSS	Total
Number of projects	120	60	180
Saving/project	$0.5M	$1.0M	$120M

(1) Robust engineering project involves optimizing existing design concept.

(2) Full DFSS project involves new design where concept is not determined.

(3) Saving includes savings in "hard" and "soft" dollars.

(4) Existing new product development processes need to be integrated into DFSS curriculum.

Figure 6.3
DFSS and RE implementation

Moreover, even within companies trained by ASI, it has been difficult to adapt Taguchi methods as an engineering strategy to prevent fires.

6.5. Fourth Period: Institutionalization of Robust Engineering, 2000–Present

Today, engineers are doing their best to rotate the design–build/simulate–Test–fix cycle. They are very busy rotating this cycle. Figure 6.4 shows what I call the "traditional product development process." The cycle starts by developing "requirements" based on vision, mission, and corporate strategies, and the voice of the customer. The house of quality for quality function deployment (Figures 6.5 and 6.6) provides an effective process to accomplish this. Then concepts are generated and selected. Concepts may have been developed previously during *seed technology*. Stuart Pugh's concept selection is an excellent process for this stage. Then a prototype is developed and tested by hardware or by simulation. It is tested against requirements; if it does not meet requirements, the design is studied and analyzed heavily. Based on what is learned, a design change takes place. Then the new design is tested again to see if it meets the requirements now. That is how the design–build/simulate–test–fix cycle goes, using iterations as needed.

This traditional process is still missing a critical step: parameter design or robust optimization. Once the design is optimized for robustness based on its energy transformation, you have the opportunity to meet all the requirements at once: that is, to kill all the birds with one stone. Moreover, chances are that you may exceed requirements by far and therefore are left with plenty of opportunities to reduce cost. On the other hand, when you optimize the design (based on its energy transformation, of course) and find that it does not meet the requirements, you have a strong indication of a poor concept. You must either reject the design

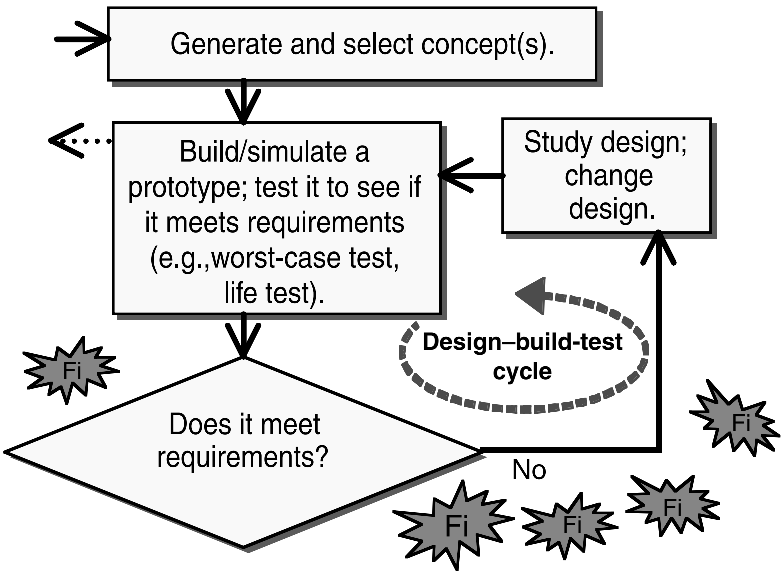

Figure 6.4
Traditional product development

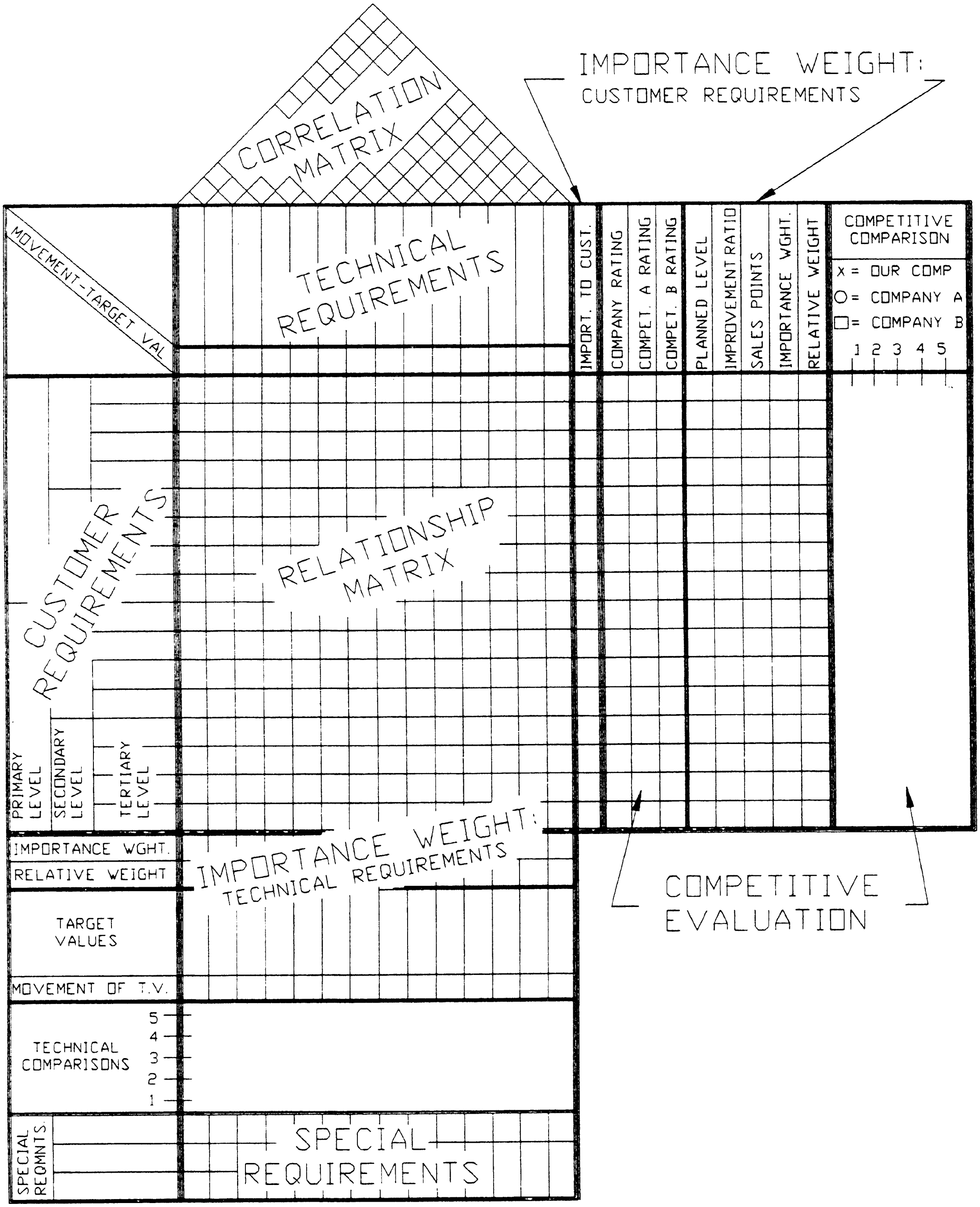

Figure 6.5
House of quality

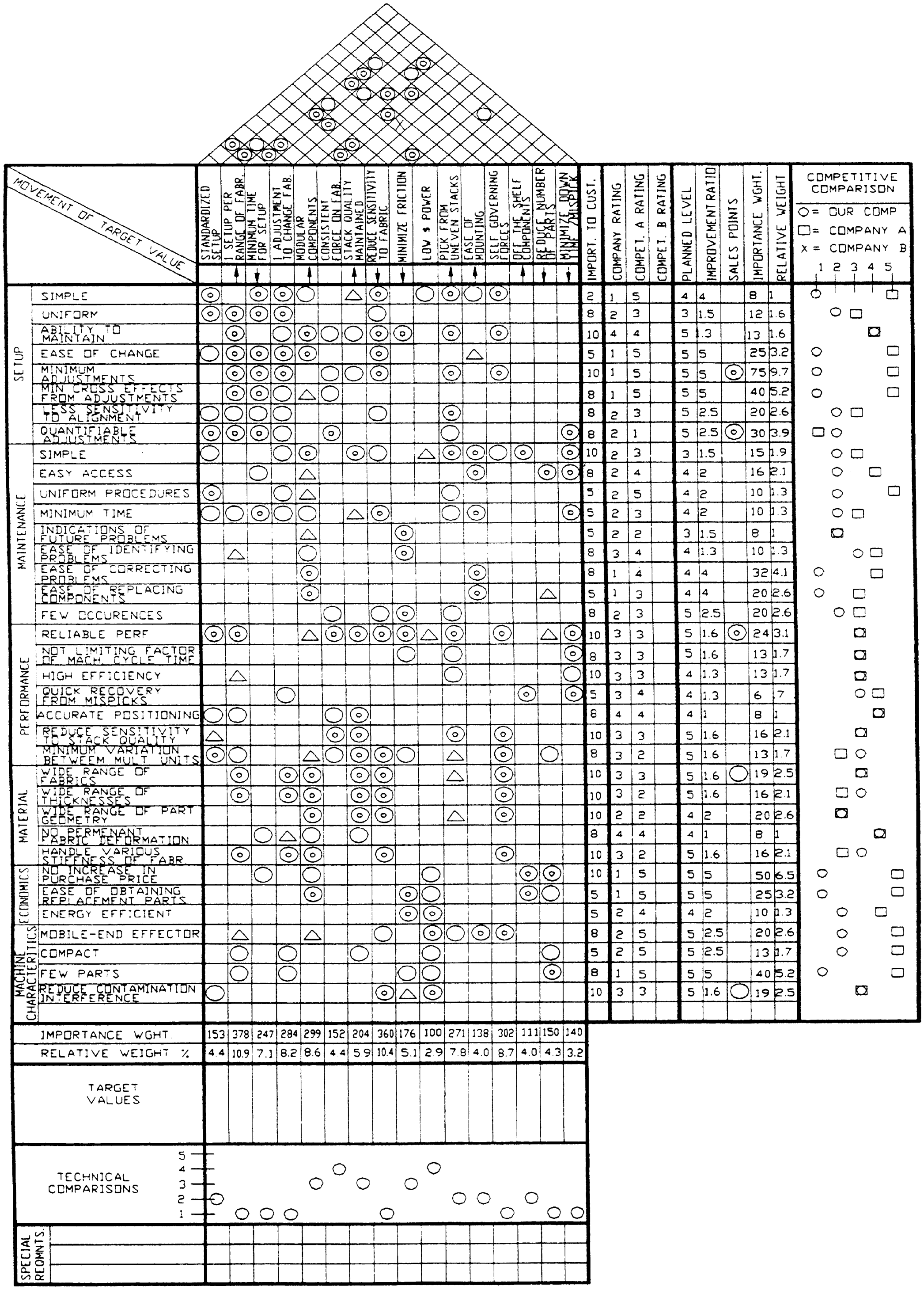

Figure 6.6
House of quality for pickup device

and change the concept, or go to the next step of tolerance design for further improvement with a minimum increase in cost. Recognizing that robust optimization seeks for perfection of the conceptual design will prevent a poor concept from going downstream, thus avoiding the need for firefighting.

In a typical company in the United States, it is said that 75% of engineers' time is spent on fighting fires. Successful firefighters are recognized as good engineers and are promoted. When one *prevents* fires, he or she will not be recognized. This is a serious issue that only top executives can resolve. Just ask anyone which is more effective, firefighting or fire prevention and I am sure that the majority of people will say that fire prevention is more effective and is the right thing to do. However, in a typical company, engineers developing technology and products are not asked to optimize design for robustness. They are getting paid to meet "requirements." Therefore, they rotate through the design–build–test–fix cycle to test against requirements. Or their job description does not spell out "optimization"; that is, nobody is asking them to optimize the design.

Figure 6.7 shows product development with robust engineering from 30,000 feet above. This process includes robust optimization of technology elements in the R&D phase. With energy thinking, technology elements can be optimized for robustness without having the requirements for a specific product. For instance, a small motor can be optimized without knowing the detailed requirements. This concept of technology robustness is highly advantageous in achieving quality, reliability, low cost, and shorter development time.

Although it has been 20 years since Taguchi methods were introduced into the United States, we cannot say that any company has changed its culture successfully from firefighting to fire prevention. Some got close, but they did not sustain the momentum. Many are working on it today, but struggling. For the sake of reducing the "loss to society," robust engineering should be "imprinted in the DNA" of engineers, so to speak. To accomplish this vision, we need to do the following:

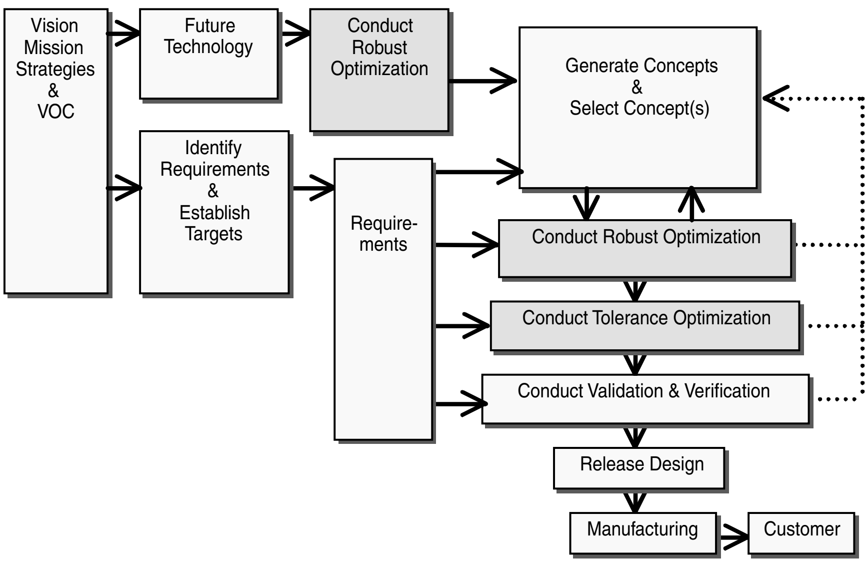

Figure 6.7
Product development with robust engineering

1. Introduce fire prevention as a corporate strategy. It is absolutely necessary to have top executives' leadership to establish a robust engineering culture.
2. Integrate robust optimization and tolerance optimization in R&D and in the product development process. Prioritize and provide appropriate resources for optimization.
3. Convince several major engineering schools to establish a solid course on robust engineering. This should not be simply one to two hours of coverage within a class on design of experiments, as many universities provide today, but at least 4 credits (about 50 hours) at the undergraduate level and a master's degree in robust engineering at the graduate level.
4. Develop networks among practitioners internationally. The Quality Engineering Society in Japan is well established. A tremendous amount of research has been accomplished by society in the last 10 years. Congratulations to all of you, but today there is no effective mechanism to exchange ideas internationally.
5. In 2003, under the leadership of Subir Chowdhury, the American Supplier Institute created the first International Society for Robust Engineering Professionals (*www.isrep.com*). Taguchi launched the society site at ASI's annual Taguchi Symposium in September 2003 in Dearborn, Michigan.

We look forward to continued growth in the area and to companies recognizing the importance of fire prevention.