Is Statistical Process Control (SPC) an important tool for improving quality and productivity? Yes. Will SPC allow American manufacturers to meet the quality and cost challenges of the future? No, not by itself. As observed by Dr. Kaoru Ishikawa, we are seeing quality activities evolve into a new generation. The first two generations, inspection and manufacturing process control, are gradually giving way to a third—product and process design improvements (Fig. 1). Two emerging methodologies are at the forefront of this movement: Quality Function Deployment and Taguchi methods.

SPC is a preventive measure, but only to a point. It addresses only the variation introduced by the production process itself. That is, SPC involves fixing what is wrong and attempting to reduce variation after release for production. Prevention and reduction of variation should begin during the design of the product and the production process.

Control charts in Japan are now one of the “Seven Old Tools” (along with Pareto analysis, cause-and-effect diagrams, data stratification, check sheets, histograms, and scatter diagrams). Mastery of these tools, and the statistical thinking that accompanies them, greatly enhances the effectiveness of Quality Function Deployment and Taguchi methods. As Dr. Ishikawa has stated, “Unless a person is trained to use these simple and elementary tools, he cannot expect to master the more difficult methods. In the case of Japan, the fact that top management down to line workers can use these seven tools is quite significant.” These “old” tools maintain quality improvements made in the design stages.

Quality Function Deployment and Taguchi methods are aimed at solving quality problems at a much earlier stage than SPC—improving product and process design before manufacture. As shown in Fig. 2, you can protect against environmental variables and product deterioration only at the product design stage. Product and process design optimization also can significantly reduce manufacturing variations. The net effect is a reduction of variation in product quality and performance as well as reduced manufacturing cost.

Tracking the Voice of the Customer: QFD

Quality Function Deployment, or QFD, is now used by many leading Japanese and American companies. First used by Mitsubishi’s Kobe Shipyard beginning in 1972, QFD assures that the “voice of the customer” is heard throughout all stages of product development. It should drive the effort of every function within a company.

In its broadest meaning, QFD is a philosophy of planning and development. Customer requirements and desires are deployed vertically and horizontally throughout the organization. Thinking of an organization as a bolt of cloth, both the vertical and horizontal weave must be equal to ensure strength. American companies traditionally have had strong vertical structure but weak horizontal communication. QFD provides that horizontal weave. More than just a function of the quality department, QFD is a potent planning system for implementing business objectives.

A fundamental goal of QFD is to eliminate startup problems and
Fig. 2. Product development stages at which countermeasures against various sources of variation can be built into the product.

early product revisions. Quality assurance thus starts with the gathering of market information and research and development. It moves through quality planning, quality design, and production preparations, and includes production, purchasing, sales, and service. All business functions are tied together horizontally. Responsibility for producing a quality item is extended (deployed) beyond manufacturing and quality control. A mechanism is put in place to accomplish it.

The meaning of “quality” expands beyond “fitness for use” or “conformance to specifications.” It includes the issues of cost and timeliness. Contrast it with traditional methods of development and production, where the executive’s or engineer’s voice drives the process and post-introduction problem solving is relied upon to fix whatever the customer doesn’t like.

QFD is not an engineering system per se, but rather a documentation and communication system.

In a narrower sense, QFD is an approach to engineering design which employs a collection of tools to systematically:

- Determine design target quality levels
- Determine critical areas where engineering resources are needed to gain a competitive advantage
- Identify design conflicts
- Assign responsibilities
- Link internal control points to the needs of the external customer
- Determine critical product component and process parameters
- Develop instructions for operating personnel.

Of course, every organization has some means of eventually incorporating customers’ presumed requirements into a final product. In this sense, QFD does not represent a totally new idea.

However, through QFD, companies do it in a very disciplined, structured manner. Usually a series of charts or matrices is used to achieve specific product objectives by translating customer requirements into design and production parameters. QFD is not an engineering system per se, but rather a documentation and communication system.

The point of departure for QFD is the voice of the customer. One of the most important tasks is to translate the customers’ requirements expressed in their own words, into detailed technical language and target values, termed “Counterpart Characteristics.” They eventually form a set of final product control characteristics. Fig. 3 shows a simplified example of a product planning matrix used as the starting point, translating customer requirements to design requirements. Competitive comparisons are integral to QFD at every stage. They help to ensure that marketing strategies or sales points don’t become diluted or altered in the development process.

The design requirements (counterpart characteristics) determined initially in the planning matrix are transferred to subsequent charts to help define part characteristics. Part characteristics, in turn, are carried on to establish the appropriate manufacturing operations, and then detailed production requirements.

In simplest terms, successively apply the Pareto principle — elaborate the details at one stage, then select the most important items for the next stage. Therefore, QFD not only tells where to concentrate engineering effort, but, just as importantly, where not to invest time and money. It also promotes “simultaneous engineering;” design, process, and manufacturing engineers work as a team to speed the progress and resolve conflicts.

As a relatively new concept, especially in the U.S., QFD is evolving rapidly. In fact, the name “QFD” is not universal. (Bell Labs, for exam-
Counterpart Characteristics

Product Planning Matrix

The voice of the customer for sewing machines further revealed that improvement in sewing starts would provide a significant competitive advantage. Then QFD targeted key design characteristics such as bed cross section and holding height for intensive engineering effort.

The new sewing machines materially improved their customers' quality and productivity. Sales leaped tremendously despite a long term decline in the sewing machine market. Tokyo Juki is now No. 1 in the world.

While many Japanese companies, including all Toyota suppliers, are using QFD, the first U.S. case studies emerged only in early 1986. However, interest is snowballing. All of the Big Three domestic auto makers have begun training and applications. Ford is strongly encouraging the use of QFD by its suppliers. Budd Company, Kelsey-Hayes and Sheller-Globe have completed case studies. Non-automotive users include such diverse companies as Omark Industries, Digital Equipment, and Proctor & Gamble.

Applications in the United States thus far have generally been modest in scope and impact. Nevertheless, success stories are emerging. Several automotive suppliers report greatly improved customer satisfaction with such products as coolant level sensors and glove boxes. QFD helped them to identify design shortcomings early in the process.

Tie-in to Taguchi

One reason QFD is so powerful is that it ranks critical items to help determine where quality technology...
and engineering effort should be applied. Also, QFD often identifies conflicting design requirements. In these instances, Taguchi methods are providing some remarkable results.

While Taguchi methods are often an integral part of QFD, they are also used extensively outside of the QFD framework. Less than one hundred QFD case studies have been documented in the United States, but there have been over 6000 Taguchi applications, and that number is growing rapidly.

Dr. Genichi Taguchi, a highly acclaimed Japanese engineer and the winner of four Deming Prizes, began developing these methods during the 1950s. His most important contribution has been the combination of engineering and statistical methods to achieve rapid product and process design optimization. Taguchi’s methods form a comprehensive, integrated quality engineering system, including a number of special techniques. However, Taguchi’s approach is here distilled to three areas:

1. Quality evaluation
2. Cost-effective quality improvement
3. Cost-effective quality maintenance.

Quality Evaluation

Taguchi defines and evaluates quality by his “loss function.” Loss refers to costs incurred or profits foregone relative to baseline performance. The underlying principle is that quality loss is proportional to the deviation from a target value (or ideal performance level) over the life of a product. Therefore, conformance to arbitrary specification limits is an irrelevant measure of quality (Fig. 4). The loss function quantifies potential savings by reducing variation around the target value.

Taguchi’s loss function contradicts the notion that everything within specs is equally good and that everything outside of specs is equally bad. A simple illustration is variation around a scheduled flight departure time. Customer dissatisfaction (and potential loss) will grow at an increasing rate as departure time deviates, early or late, from the published schedule. We can assign no arbitrary limits to distinguish zones of total satisfaction (no loss) from total dissatisfaction. Assume our standard on the “late” side is “no greater than 30 minutes.” A delayed passenger certainly sees no black-and-white difference between a delay of 29.5 minutes and 30.5 minutes, and therefore our “spec” is a useless measure of customer satisfaction.

As a product example, consider the color density of a picture tube. It is unreasonable to assume that customers are equally satisfied with all levels of density within a given specification interval, only to become totally unsatisfied when the density reaches some discrete point. Suppose that two plants producing the same picture tube shipped units with the same average density and all were within specifications. Both plants’ customers should be equally satisfied, right? The Sony Corporation found out differently. Customer satisfaction was higher and warranty claims were lower for units produced in its Japanese plant than those produced in its American plant. The difference was deviation from target value. Average density was the same, but dispersion in density values was much greater for the American-produced units.

The above examples are cases where “nominal is best.” The loss function also applies to “larger is better” situations (such as tread life, weld strength) and to “smaller is better” (such as fuel consumption, CO content of exhaust gas).

Using the loss function, all quality improvements are measured in terms of cost savings. Cost and quality improvement become one and the same. Quality projects may be undertaken even though no out-of-spec material is being produced. Conversely, you may reject an improvement project in favor of others even when some out-of-spec material is being produced. This view of quality greatly promotes the incessant devotion to reducing variation and continuous improvement which accounts for Japan’s rise as a global quality and cost leader.

Cost-Effective Quality Improvement

The “how to” of improvement consists of three steps applied to both the product design and production processes:

1. System design — a non-statistical process of surveying and selecting appropriate design technology and concepts to produce a prototype design that possesses the functions required by the product plan
2. Parameter design — experimental design methods to find the optimal levels of the individual system parameters which were determined during the system design

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\text{Continuous Loss Function}
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Fig. 4. The loss function quantifies potential savings by reducing variation around the target value.
3. Tolerance design — experimental design methods, used only after parameter design, to set the tolerances of the parameters, if necessary. According to Taguchi, “narrow tolerances should be the weapon of last resort to be used only when parameter design gives insufficient results.”

Taguchi refers to them collectively as “off-line quality control.” Of the three, U.S. companies have applied parameter design most extensively. The premise behind parameter design is strikingly simple—that it is much easier and less costly to design a product insensitive to manufacturing variables than to control all of those variables. Similarly, parameter design can improve a product’s field performance so that it is less subject to environmental variables and deterioration. The objective is a “robust” design.

As an example of parameter design, Taguchi often cites the case of the Ina Tile Company in 1953. Ina knew that uneven temperature distribution in the tunnel kiln was an assignable cause of size variation in the fired tiles. Rather than attempt to control the kiln temperature, which would have been expensive, they performed a design experiment. The experiment studied the effects of varying seven factors involved in the tile mixture. They found that changing the lime content from one percent to five percent reduced tile size variation by a factor of ten, obviating the need for expensive temperature controls.

For parameter design, Taguchi modified the conventional statistical methods of experimental design. The basic strategy is straightforward:

- Identify which factors are controllable and which are “noise” (not controllable or very expensive to control)
- Find the levels for controllable factors such that highest performance is achieved in spite of the noise.

The power of Taguchi methods is ability to greatly improve design or production processes in a short time, using a relatively small number of experiments (combinations). Traditional techniques, checking the effects of only four factors, each at three different settings, demand 81 combinations. A corresponding Taguchi experiment uses only nine combinations. This difference grows exponentially as more factors are added to the analysis. Using Taguchi methods, a small number of confirmation experiments are usually performed to check initial experimental conclusions.

Companies have applied Taguchi parameter experimentation to the controllable factors in an existing production process without modifying the product design itself. Ford Body and Assembly Division improved door fits under existing production constraints in one of its plants. They had only four factors with which to work (such as latch plate location), yet they managed to improve on three of five targeted quality characteristics, with no capital investment or design changes.

ITT used Taguchi methods to increase the weld-splice strength in wire harness assemblies until it exceeded the core strength of the wire. Not only did they save $300,000 per year by discontinuing a destructive pull test, ITT also reduced field failures and discarded proposals for costly alternative processes such as ultrasonic welding.

Cost-Effective Quality Maintenance

Even when product and process design are completely optimized, tools wear, people make mistakes, and materials vary. To maintain quality during production, Taguchi has developed “on-line quality control.” It relies on several formulas to cost-effectively minimize losses due to piece-to-piece variation: scrap, adjustment, inspection, and manufacturing-related performance variation. The basic principle is to weigh the cost (loss) of reducing variation around the target against the loss due to the variation itself. This form of quality control does not involve any charts but rather a systematic method of checking and adjusting. On-line quality control is poorly understood in the United States and not practiced, even though it is well-suited to operations such as metal stamping.

... parameter design can improve a product's field performance so that it is less subject to environmental variables and deterioration.

Perspectives On Taguchi

Of course, Taguchi is not without critics. Some charge that certain methods are statistically incorrect or inefficient, and sometimes give the wrong (not “the best”) answers. The argument may represent the difference between, say, a 50 percent improvement in two months versus a 90 percent improvement in two years. In reality, with a complex product or process, the full conventional experimental protocol is almost never performed and seat-of-the-pants judgments suffice.

While the arguments over his statistical procedures have merit, Taguchi has made statistical experimental design usable by a wide range of non-statisticians, so his methods are having a great impact on American manufacturing. ITT, for example, used Taguchi methods in over 2000 cases and reported cost savings of $35 million. Other cases of six- and seven-figure cost savings abound. A recent two-day Detroit conference on Taguchi methods and QFD drew a full house of 250 people and many more were turned away.

More telling is Akashi Fukuhara's analysis of the sources of quality improvement at Toyota from 1977 to 1985. Fukuhara is vice president of the Central Japan Quality Association and the retired manager of product assurance at Toyota Autobody. He attributed fully 50 percent to Taguchi’s parameter design. SPC was little more than a footnote in his analysis. He believes that many other Japanese firms would give a similar breakdown. And perhaps Taguchi's conceptual framework for quality improvement is even more important than his statistical techniques.
Relationships Among QFD, Taguchi Methods, and JIT/TQC Operating Principles

Customer
- Market quality requirements
- Product concepting

Product Development Stream
- Design engineering
- Process engineering
- Manufacturing
- Assembly
- Sales/service

JIT/TQC principles (elimination of waste)
- SPC
- Fallsafing
- Quality at the source/immediate feedback
- Standardization
- Setup reduction
- Employee involvement
- Education/training
- Mfg. cells/group technology
- Preventive maintenance

QFD
(Voice of the customer)
Product planning matrix*

Taguchi methods
(Loss function concept/reduction of variation)

Off-line QC
A. System design
B. Parameter design
C. Tolerance design

On-line QC
reduction of piece-to-piece variation

* Product planning matrix is shown in Fig. 3.

Fig. 5. The voice of the customer begins with the product planning matrix and continues through succeeding sets of matrices (product design, process planning, and production planning). The total number of matrices in a complete product development stream can be very large.

Conclusion
QFD is an appropriate mechanism to integrate the principles and methods of world-class manufacturing. As shown in Fig. 5, the voice of the customer selectively guides the application of efforts to eliminate waste and foster continuous improvement using Taguchi methods as well as JIT/TQC operating principles.

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