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Report No. 27

ON QUALITY PRACTICE IN JAPAN

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December 1987

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PRACTICAL SIGNIFICANCE

We recently visited Japan to learn about training in quality improvement methods in Japanese industry and about how these methods were used in product and process design. We met with designers, trainers, and quality professionals from seven high-technology manufacturing companies and three trade and professional organizations. In this paper, we discuss what we learned on the following aspects of quality practice in Japan: training and education in quality improvement methods in industry, use of statistical methods in product and process design, key elements of their product realization process, and efforts to promote quality by individual companies as well as by the industry as a whole.

Key Words: Engineering education; statistics; design of experiments; quality management.

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On Quality Practice in Japan

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1 Introduction

We visited seven high-technology manufacturing companies and three trade and professional organizations in Japan over a two week period in June 1986. The primary goal of our trip was to learn about training and education on quality improvement methods in Japanese industry and how these methods were used in product and process design. The trip was part of a joint AT&T Bell Laboratories and University of Wisconsin research project funded in part by the National Science Foundation. One of the objectives of this project is to direct statistical research to quality and productivity problems in industry and to bring an understanding of engineering problems in product and process design to the statistical community. During the course of this effort, we visited some high-technology companies in Japan to observe first hand how quality is practiced in Japanese industry.

The companies we visited were Nippon Denso, Toyota Motor Co., Sharp, Fuji-Xerox, NEC, Texas Instruments (Japan), and Ricoh. We also visited three trade and professional organizations: the Central Japan Quality Control Association (CJQCA), the Japanese Standards Association (JSA), and the National Research Laboratory of Metrology (NRLM). We met with design engineers, trainers, and quality professionals from these organizations, discussed case studies, visited plant sites, and observed some of the operations. In this paper we discuss what we learned on the following key aspects of quality practice: training in quality improvement methods in industry, use of statistical methods in product and process design, important elements of their product realization process, and efforts to promote quality in industry.

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The influence of Dr. Genichi Taguchi helped us in getting excellent cooperation from the organizations we visited. He is a consultant to most of these organizations. Inevitably, however, this implies that our impressions are most valid for this part of the Japanese industry. We have tried to indicate in the paper, wherever appropriate, practices that are representative of the industry as a whole and those that we believe to be common only to one or more of the companies we visited.

2 Training

Japanese industry has made a major commitment to training its employees in quality improvement methods. More than 100,000 engineers are trained in one year; about 33,000 people in the Central Japan area alone. Quality curricula cover a broad range of topics and show that all parts of the companies are participating in quality improvement activities.

2.1 Curricula

Many of the companies we visited had similar quality training programs, probably because they were all shaped in the image of a single model, the curriculum of the Japanese Union of Scientists and Engineers (JUSE). A sample program from CJQCA is shown in Table 1. The programs of individual companies we visited seemed to be very similar to subsets of this curriculum, so we can use Table 1 as a reference for making comments that apply to many Japanese companies.

Notice that the curriculum includes courses for a broad range of job functions and management levels. The CJQCA offerings include courses on quality philosophy and methods for executives and managers, and separate courses on basic quality improvement methods for engineers, factory foremen and shop floor employees, and for sales and clerical functions.

For engineers, the core of the quality program is the *QC Basic Course*, a 30-day course covering quality philosophy, Quality Function Deployment (see Sullivan, 1986), the basic seven tools (Ishikawa, 1982), the new seven tools (see Brassard, 1986), and introductions to design of experiments, robust product and process design (Taguchi, 1986), reliability, analysis of variance, and regression. We were told in several companies that every engineer takes this course. In fact, a general manager for quality control at one company said, "If you don't know QC, you're not an engineer."

In addition to the QC Basic Course, engineers may take advanced instruction in design of experiments and reliability. The courses on design of experiments at the companies we visited use Taguchi's book (1976), and cover simple one-way and two-way layouts, orthogonal arrays, and analysis of variance. Taguchi's S/N ratios also appeared prominently on several course syllabi. The advanced topics were typically also covered at a superficial level in courses for managers, so that these managers can encourage and guide the work of their subordinates.

2.2 Course Format and Length

A striking difference between the quality training programs in the Japanese companies we visited and those in many U.S. companies is the length and format of the courses. In the Japanese companies, courses meet several days per month over a period of many months. Between class sessions students work on homework assignments. The total class time in these courses is quite large. For example, the QC Basic Course lasts 188 hours (spent in six hour days spread over five months), and the advanced Design of Experiments Course lasts about 130 hours (spread over five to six months). In many cases this format is made possible by close geographic location of factories, design offices, and training personnel.

In contrast, U.S. training programs are usually built around the short course format, with students immersed in the subject matter for one to five days, and returning to their normal jobs at the end of that period.

2.3 Instructors and QC Advisors

Instructors of quality courses are usually experienced engineers from inside the company, or, sometimes, outside experts and consultants. In some companies, a specially trained engineer, called a QC advisor, acts as a co-instructor and consultant to the students. The QC Advisor is typically a member of an engineering organization who, after attending the QC Basic Course, went on to take advanced courses on design of experiments and reliability. This engineer is nurtured into becoming a quality methods resource for the whole engineering organization. Several years of teaching and consulting is considered essential before one becomes a QC advisor.

2.4 Role of Applications

Applications play an important role in quality improvement instruction, and Japanese companies make extensive use of case studies in their courses. The case studies are drawn from a company's own experiences. More than once during our visit, engineers involved in training hauled out large notebooks filled with case studies for reference. This is an example of the kind of documentation of results and accumulation of knowledge that is valued in Japanese companies.

Students are often expected to apply the methods they learn in a course to problems in their regular job. At one company, the course ends with the student and manager sitting down to identify a suitable project. After three months and again after six months the student gives progress reports on the project to the manager. The QC Advisor is often involved in these projects, guiding the student in applying the methods he or she has just learned.

2.5 Software

At CJQCA we did not see evidence that software is used much in training. Instead, much importance seems to be placed on knowing the formulas and calculations.

Although we understand that JUSE (Japanese Union of Scientists and Engineers) has developed a series of quality control programs for the NEC PC, we saw very little emphasis on statistical computing or graphics in the training programs at the companies we visited. This is an area in which Japanese training methods could be improved.

3 Use of Statistical Methods

Having heard so much about the mania in Japan for collecting data, we wanted to see first hand how they used statistical methods, especially design of experiments, in product and process design.

3.1 Experimental Design

We came away extremely impressed at how widely experimentation was used in Japanese companies. In one of the companies we visited, more than 6,000 experiments had been conducted in one year. Although some of these were done as part of course assignments, this is still very impressive. In another company, during the design and development of one product over a three year period, the design engineers had conducted forty-eight multifactor experiments. The chief engineer of this product told us that the use of planned experiments was the single most important factor in being able to develop such a high quality product. Multifactor experiments seem to be an integral part of the design process in Japanese companies.

A large portion of the experiments conducted are the traditional ones which analyze the mean responses and use fractional factorial designs and other orthogonal arrays like the L_{18} and the L_{36}. ANOVA tables and plots of marginal means are used in the analysis. They do not, however, rely entirely on significance testing in choosing the factors and levels. Results from statistical analysis are calibrated against engineering judgement before final decisions are made.

We did not see any case studies or courses on response surface designs. The users are also not familiar with many of the useful data analysis tools such as graphical displays of data, diagnostics, Daniel's half-normal plot, and the study of interactions and aliasing structure.

3.2 Methods for Robust Product and Process Design

Taguchi's parameter design method for robust product and process design was popular in most of the companies we visited. (This could be in part because Taguchi was a consultant to these companies.) The majority of the forty-eight multifactor experiments mentioned earlier were conducted to make the product robust to operating and environmental variations. There was, however, a wide variability among the companies in the extent to which robust design was used.

The percentage of parameter design experiments using control and noise arrays was small. Most of these had been conducted recently but their usage is increasing. Engineers seem to find linear graphs for selecting the designs to be appealing because of their geometric nature but do not appear to be aware of other methods. Linear graphs become complicated for designs larger than L_9 and L_{16}. Some of Taguchi's ideas, such as his various S/N ratios, seem to have been introduced only recently in some companies. They are becoming popular, but in most instances the users appear to follow Taguchi's recipe without questioning its rationale. In particular, they seem unaware of the idea of data transformations and their relationships to S/N ratios (Box, 1987; Nair and Pregibon, 1986). See also related work by Kackar (1985); Leon, Shoemaker and Kackar (1986), and Phadke and Dehnad (1986). During our discussions, the engineers reported successes in all cases but it was not clear how frequently it failed to address or solve the real problems.

There were a substantial number of case studies in which the responses were in the form of ordered categorical data. Taguchi's accumulation analysis appears to be the standard method for analyzing such data in the companies we visited. They are not familiar with any of the methods that are available in the literature for analyzing ordered categorical data (see, for example, Fisher, 1925; Davies, 1958; and Agresti, 1984). They are also not aware of some of the deficiencies in the accumulation analysis method that have been pointed out recently (Box and Jones, 1986; Hamada and Wu, 1986; Nair, 1986).

3.3 Other Methods

We also saw case studies that had used regression and multivariate analysis methods. These techniques are taught to the engineers as part of the Design of Experiments Course. Many of the tools in applied multivariate analysis and exploratory data analysis that are commonly used in the U.S. do not seem to have been taught or used in the companies we visited. However, from a JUSE course outline on multivariate analysis, it appears that these techniques are taught at other organizations. The engineers are familiar with techniques for reliability prediction, failure mode effects analysis (FMEA), and fault tree analysis (FTA). Most of these are, unfortunately, not taught or emphasized in our statistics curriculum.

In our discussions with engineers and quality control personnel, we had focused on the use of relatively advanced statistical methods, such as the design of experiments, in product and process design. However, we should emphasize that Japanese companies do not underestimate the usefulness of simple quality improvement methods like the basic seven tools (Ishikawa, 1982). In a design department at one company, approximately half of the quality improvement activity involved the use of these simple tools. Quality function deployment (see Sullivan, 1986) is also an important systems engineering tool during product design. The use of the new seven tools (see Brassard, 1986) is not widespread at present.

One area in which they are lagging behind is statistical computing and the use of software for data analysis. The few statistical software packages available in the market are not comparable to the leading ones in the United States. Very little attention is given to exploratory data analysis, diagnostics, graphics, and other methods that have become routine data-analytic tools in the West.

4 Product Realization Process

We were given excellent insight into the product realization process of one company. Although the discussion in this section is based mostly on what we learned from this company, some of the practices discussed below were also followed during product realization in the other companies we visited.

4.1 Chief Engineer

After a successful market feasibility study, a chief engineer was appointed to oversee the entire product realization process: from product planning, design and manufacturing to sales and customer service. The chief engineer's responsibility and accountability extends to all phases of the process. He ensures continuity and a smooth transition from one phase to the next. Some team members from one phase go on to form part of the team for the next phase. This helps in the smooth transition and provides for more teamwork among the various groups. The chief engineer from this company likened the situation in the U.S. to a team of rugby players tossing the ball from one to another like a hot potato without realizing that it is eventually going to come back to them.

4.2 Collection of Data on Market Conditions

Before designing the product, the engineers familiarized themselves with potential operating, environmental, and market conditions of the product. A small team of engineers visited the different markets for the product and interviewed potential users. They collected information on the operating conditions such as temperature, humidity, and dust, and market conditions such as size and shape of paper to be used in copying machines. In addition, they have direct access to the information from the market research study conducted by the marketing organization and to data bases on past records of similar products. They also collected information on estimates of customers' losses that could result from the product's failure. These cost estimates play an important role in determining the level of the product's quality.

4.3 Concept Design

During concept design, the product was divided into modules and submodules, and for each (sub)module, the appropriate functional characteristics were identified. Target values for the responses, methods for measuring the responses, and losses associated with the deviation of responses from target values were also determined. Failure modes of each module and the criticality of these modes were assessed. Different technologies and designs for the entire product and each module were evaluated. When decisions were obvious, they were adopted immediately; otherwise, they were deferred to the product design stage.

We learned that in this company the basic technology was typically copied from an American collaborator or competitor. Quality function deployment (Sullivan, 1986) was an important systems engineering tool used during concept design to translate customer needs into engineering specifications. After concept design was completed, the company's top management examined the product's economic and technological viability and decided whether to proceed further.

4.4 Role of Planned Experiments

Experimentation was a key quality technology for building quality into the product during the product design stage. We have already mentioned the example where forty-eight multifactor experiments were conducted during the development phase of one product. Each of these experiments was used to study simultaneously from two to thirty different design parameters. Either a QC advisor within the engineering department or a member of the QC department consulted with the engineers in planning and conducting the experiments and in analyzing the data. In addition, an outside quality expert was often invited to review the plans for the experiments and the results of the subsequent data analysis. Most of the design engineers were familiar with the basic principles of experimental design from taking the Basic QC Course. In addition, many participated in *E*-activities, which are periodic meetings led by a QC advisor to review results of past experiments and to further the knowledge of experimental design.

Taguchi's ideas on robust design have made experimentation even more effective. During parameter design, each module and submodule was first made robust against environmental and manufacturing variations and deterioration. The results were then integrated to design the whole system. This is typical of the Japanese approach where quality is built into the product during the design stage.

5 Promotion of Quality

Many of the quality promotion activities in Japan are aimed at motivating the people, improving their skills, and providing better job satisfaction. The leaders of Japanese companies and industry realized long ago that these are essential to improving quality and productivity in the long run.

5.1 Industry Level

Many individuals have influenced the way quality is practiced through their teaching, consulting, organizational and leadership activities. Organizations such as JUSE and JSA at the national level and CJQCA and others at the regional levels have also played a key role in promoting quality. The most important service they provide is, of course, training and education. In addition to providing their own courses, the curricula of JUSE and JSA form the basis for the in-house training programs of the companies. These organizations also provide a forum for the discussion and dissemination of quality methodology by organizing meetings and seminars and publishing journals. There seems to be a spirit of cooperation as well as competition between the various trade organizations. For example, the leading quality experts and consultants are members of both JUSE and JSA as well as other regional organizations.

Quality recognition awards, commendations, and ceremonies play a major role in promoting quality in Japan. Among these, the Deming Prizes, established by JUSE in 1951, have had the most impact. They were initially set up to promote statistical quality control. Now they cover very broad company-wide quality control activities. There are four different categories of Deming Prizes: i) Deming Prize for individual persons; ii) Deming Application Prize for large enterprises; iii) Deming Application Prize for small enterprises; and iv) Deming Application Prize for a division of a company.

The Deming Prize for individuals recognizes the leaders of the Japanese revolution in quality. By 1985, about fifty Japanese quality experts had received the award. The Deming Application Prize awarded to companies is a qualifying award. Any company can qualify by satisfying the criteria set by the Deming Prize Committee. These criteria are based on all aspects of the business – from management policies, organizational systems for supporting quality activities, education and training, standardization, and quality planning to the use of statistical methods and future plans for improvement. A company's success in qualifying for the Deming Prize is widely publicized in major newspapers, national radio, and television.

By 1985, many major Japanese companies had received the Deming Application Prize. In anticipation of this, JUSE had set up the Japan Quality Control Medal in 1970. A company can only apply for the Japan Quality Control Medal five years after it has won the Deming Prize. The idea is to encourage the companies to continue to improve quality even after they have received the Deming Prize.

5.2 Company Level

Following the advice of Deming in the 1950's, the Japanese companies began their focus on quality with statistical quality control. But the managers soon realized that effective quality control is necessarily a company-wide activity. They, therefore, started promoting quality control in all functional areas of the business – from product planning and design all the way to sales and service. The management philosophies, policies, and procedures are all aimed at improving the plan and operations of the work process to attain high standards of quality and productivity. The emphasis is on eliminating (or building in countermeasures against) the causes of quality problems, and simplifying the work process to eliminate all unnecessary and wasteful operations. The efforts at company-wide quality control were clearly evident during our discussions with the managers and during our visits to the plant sites. Due to its strategic importance, quality control activities are run by the top management. The general manager of the QC department is equivalent to a vice-president.

The QC circles in Japan are a good example of how workers participate in the decision-making process in the company. QC circles are small groups of plant workers who voluntarily organize regular meetings to solve problems in the work process and to help workers derive greater satisfaction from their jobs. These circles are quite popular in Japanese companies. For example, Toyota Motor Co., which has 65,000 employees, has about 6,000 circles. In addition to product quality, QC circles also deal with issues such as cost, safety, and work environment. The top management encourages and actively promotes the activities of the QC circles by arranging periodic meetings of the different circles and by giving commendations to recognize outstanding achievements.

Some Japanese companies also promote quality among their suppliers and subcontractors by establishing their own quality recognition awards. For example, Toyota Motor Co. has two awards: the Excellence award and the Superiority award. These awards are patterned after the Deming Prize and the Japan QC Medal given nationally.

6 Conclusions

It was evident during our visit that Japanese management realizes the importance of statistical methods, both simple and complex, for quality improvement. It has a major commitment to training its employees, particularly engineers, in these tools. It encourages and insists on their use on a massive scale.

In the companies we visited, experimental design is used widely and very successfully during product and process design. It is likely that even greater impact may have been possible by a) employing a wider range of techniques for design and analysis, and b) making greater use of computers, graphics, and interactive data analysis.

There are some valuable lessons to be learned from the training methods used in Japanese industry. We in the U.S. need to emphasize both simple as well as advanced tools in our training programs. The training in Japan is closely tied with product development and process design organizations, and there is extensive use of case studies directly related to the students' work environment. One of the striking things we observed during our visit was the organized accumulation of knowledge and case studies in the companies. The follow-up program used in one company is an effective way to ensure that the students actually apply the tools that they learn to problems in their job environment. Having a quality methods resource person, like a QC advisor, within each engineering organization is likely to further encourage the use of quality improvement tools.

Quality is a multidimensional concept, and there are indeed a variety of reasons for the success of the Japanese industry. Not all of these are relevant or applicable to the United States. Nevertheless, we need to evaluate all novel ideas, adopt the useful ones, and modify others, whenever possible, to suit our environment and to take advantage of our strengths.

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Table 1: Central Japan Quality Control Association Partial List of Courses

Course	Length (Hours)	Capacity	Fee (Yen*) for Members
QC Seminar for Management	48	70	100,000
Total Quality Control Seminar for Management	24	40	50,000
QC Basic Course	188	70	200,000
Elementary QC Seminar	52	70	73,000
QC Seminar for Foremen	40	50	63,000
On-Line QC Seminar for Manufacturing	36	30	60,000
QC Circle Course for Administrators	22.5	60	30,000
Elementary QC Circle Seminar	19	50	30,000
QC Seminar for Sales and Clerical Area	24	40	45,000
Quality Engineering for Management	12	30	30,000
Elementary Design of Experiments	37.5	40	68,000
Design of Experiments	130.5	50	180,000
Reliability Seminar for Management	24	35	52,000
Elementary Reliability	24	30	42,000
Reliability	60	40	95,000
FMEA/FTA Methods and Case Studies	12.5	60	30,000

* (US $1 ≈ 160 Yen in June, 1986)