Part II

# Quality Engineering: A Historical Perspective

# 5 Development of Quality Engineering in Japan

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## 5.1. Origin of Quality Engineering

As an explanation of the origin of quality engineering in the post–World War II rehabilitation period in Japan, Genichi Taguchi said the following about his experiences at the Musashino Telecommunication Laboratory of the Nippon Telegraph and Telephone Public Corporation in his book, *My Way of Thinking* [1]:

> It was in 1948 when the Telecommunication Laboratory was founded in the Ministry of Communications (later Ministry of Telecommunications). The Electrotechnical Laboratory, which had supported Japanese communication and electrical research so far, was dissolved and developed into the Telecommunication Laboratory, focused on studying telecommunications. Behind the scenes, there existed a strong intention of the Common Communication Support (CCS) of the General Headquarters (GHQ).
>
> As soon as The CSS entered into Japan, it started to investigate the communicational situation in Japan. This must have been because they considered reinforcement of a communication network essential for the U.S. occupation policy. At that time, the telecommunication infrastructure in Japan was poorly established insomuch as a phone in Japan was ridiculed as a "bone." While the CSS recommended a drastic

improvement in Japanese telecommunication research, it requested foundation of a research organization such as the Bell Labs in the U.S. As a result, the Japanese government founded the Telecommunication Laboratory using 2.2 percent of the national budget.

It was in 1950 when the laboratory completed a full-scale research organization by renewing a disaster-stricken building into a new building in the ex-Nakajima airplane factory in Musashino-shi. In those days, the Japanese economy was accelerating its rehabilitation speed due to the Korean War that broke out in June of 1950. Accordingly, demand for subscribed phones began to skyrocket. Therefore, to build the telecommunication infrastructure was one of the most urgent national projects.

During this period, I entered the Telecommunication Laboratory. Because it completely followed the system of the Bell Labs, I noticed that it was an R&D laboratory, much more Americanized than expected in Japan at that time and filled with a liberal atmosphere.

At this point, I would like to mention its peculiarity. In line with inauguration of the Nippon Telegraph and Telephone Public Corporation in 1952 (currently known as NTT), the Telecommunication Laboratory also came under its control. The special characteristics of the Telecommunication Laboratory were equivalent to those of the Nippon Telegraph and Telephone Public Corporation, different from other common companies.

What are required for telecommunication are telephone machines, telecommunication networks, and exchangers. Although we conducted research and development regarding hardware and system design at that time, we did not produce actual products. By receiving design drawings and specifications from us, private manufacturers such as Nippon Electric or Fujitsu manufactured products based on them. After the Nippon Telegraph and Telephone Corporation purchased all of them, exchangers and cables were used by ourselves, and telephone machines were lent to subscribers. That is, we were "consumers."

Once exchangers broke down or cables malfunctioned, we had to squander a tremendous amount of labor force and expense. When telephone machines went out of order, we had to repair them free of charge or replace them with new ones. Those who got into trouble when these failures happened were ourselves as consumers. However, since we designed them on our own, there were no other people to make complaints against.

On the other hand, usually manufacturers sell their products produced. In other extreme words, "Everything is done once a product is sold." Thus, they do not need to seriously consider the issues of quality or cost of products after customers purchase them. In fact, quality management implemented by many of the manufacturers deals not with customers' issues but with production issues in most cases. From the viewpoint of economy, these approaches make a great difference.

If a product breaks down, we suffer from a loss—human beings are quite sensitive to their own interests. Therefore, we have no other choice but to consider how we can design a product before mass production of it, so that it does not cause failures and troubles.

Then, how we can prevent such failures and problems or what types of test should be implemented to do so becomes a critical issue. The design of experiments that I instructed was a method of conducting a test and make an improvement.

So to speak, this can be regarded as the origin of quality engineering. That is, the quality engineering defines the following: "Quality of a product is a loss given to a society after it is shipped."

This definition is seen in the journal *Standardization and Quality Management* (1965) [2]. When "the Taguchi method" was discussed in the Japanese Quality Control Society in 1986 [3], it was discussed whether the above definition agreed with the one defined by the quality control group, which said: "an entity of unique characteristics or performances to be evaluated for determining whether a product or service satisfies its objective in use." JIS Z-9011, *Single Sampling Inspection Plans by Attribute with Adjustment* (1963), regarding sampling inspection created under this new definition, was not often recognized by experts in sampling inspection. However, it proposed an epoch-making idea that loss is economically balanced based on the break-even point.

While I was watching many researchers doing their jobs in the Musashino Telecommunication Laboratory, it was noticed that most of the time spent was not on researching the idea itself but on the evaluation of the idea, such as spending their time on calculation, experimentation, prototype preparation, or testing. In order to rationalize and make the evaluation efficiently, the book *Design of Experiment* [4] was published. This book is considered to have originated from the educational textbook for engineers of the laboratory and related companies and had a strong impact on development of the design of experiments in Japan. When it was updated from the original edition of 1957 to the second one of 1962, the outlook of the design of experiments as a technical procedure was fostered from the conventional one as a phenomenal analysis. In addition, when its third edition was published, the *Design of Experiments* clarified its position as a methodology of technological development by introducing the concept of SN ratio. While it is still regarded as a heresy by experts in the statistical design of experiments, it is highly evaluated as the most creative method. However, the concept of SN ratio was already proposed in a different form in the first edition of *Design of Experiments;* Vol. 2. That is, the fact that there already existed a methodology from the beginning has perplexed many people after its new proposal was offered.

For example, the objective of using orthogonal arrays in the design of experiment is not for optimizing experimental conditions but for finding faults of experiments by the utilization of interactions. Such an idea existed from the very beginning. This contradicts the statisticians' view that interactions are neglected by Taguchi. Conversely, the new definition of quality leads to the idea that we should predict *before* product design whether or not the quality of a product will be sufficient after it has debuted in the market. From the current standpoint of quality engineering, we take it for granted that in the 1960s, when quite a few people argued that an orthogonal array should be used because of its effectiveness in technical optimization or that it could not be used because of the existence of interactions, the idea that we should take advantage of the fact that an orthogonal experiment tends to fail more frequently than a normal one could not be comprehended by ordinary engineers. [5] Quality engineering advocates that it is worthwhile to discover failure in the early phase of each experiment.

Quality engineering is often said to be difficult to understand. One of the reasons is related to its concept, another to its analysis procedure. Following is a summary of the history of change and development of quality engineering:

- *1957:* Genichi Taguchi's *Design of Experiments* was published [4]; Taguchi proposed the idea that the orthogonal array should be used to check experiments [5]; Taguchi proposed the prototype of the *SN ratio.*
- *1966: Statistical Analysis* was published [6]; *Process Adjustment* was published; Taguchi proposed the SN ratio.
- *1967: Production Process Control* was published [5]; a design quality control system during production was introduced.
- *1972: SN Ratio Manual* was published [7]; experiments on vehicle drivability, plastic injection molding, and cutting were performed.

- *1975:* Correspondence course on the SN ratio was begun [8]; application of the SN ratio to design and machining was accelerated; The term *quality engineering* was born.
- *1980:* The term *Taguchi method* began to be used in the United States; Taguchi succeeded in experiments at Bell Labs [9].
- *1984: Parameter Design for New Product Development* was published [10]; the ASI Taguchi Method Symposium began; 13 serial articles, “Evaluation of SN Ratio in Machining,” appeared in *Machine Technology* (Nikkan Kogyo) [11].
- *1985:* A research group was dispatched to Japan by Bell Labs; 12 serial articles, “Design of Experiments for Quality Engineering,” appeared in *Precision Machine* [13]; Taguchi proposed decomposition of $N\beta$.
- *1986:* JIS K-7109, *Rules of Dimensional Tolerances of a Plastic Part* was established; Taguchi–Fujikoshi Award for Measurement in Management was founded; Taguchi insisted that research on product development should be stopped.
- *1988: Quality Engineering Series* began to be published [14]; research on quality design systems in next-generation production systems was implemented by the Advanced Machining Tool Technology Promotion Association [15]; Taguchi proposed that research on technological development should be started.
- *1989:* Taguchi proposed *transformability* [16].
- *1990:* Taguchi proposed *generic function*.
- *1991:* The Quality Engineering Symposium at Ueno Ikenohata Culture Hall resulted in success; Taguchi’s *Quality Engineering for Technological Development* was published [17]; JIS Z-9090, “*Measurement: General Rules for Calibration System* was added; Taguchi stated that to get quality, don’t measure quality”; Taguchi proposed electrical characteristics, chemical reaction, and the MTS method [12].
- *1993:* Quality Engineering Forum was founded [18]; Quality Engineering Award was founded by the Precision Metrology Promotion Foundation.
- *1995:* Taguchi proposed an evaluation method based on electric power [19].
- *1996:* JIS Z-8403, *Product Characteristics: General Rules for Tolerancing* was added; 9 serial articles, “Quality Engineering for Mechanical Engineers,” appeared in *Machine Technology* (Nikkan Kogyo) [20].
- *1997:* ISO standardization of quality engineering began to be discussed [21]; Genichi Taguchi was elected to the American Automotive Hall of Fame [22].
- *1998:* The Quality Engineering Forum was renamed the Quality Engineering Society; the Quality Engineering Taguchi Award was founded [23].
- *1999: Technological Development in Chemistry, Pharmacy, and Biology* was published [24].
- *2000: Technological Development in Electric and Electronic Engineering* was published [25]; Taguchi was elected “Quality Champion in the 20th Century”; Taguchi made a new proposal for applying quality engineering to simulation [26].
- *2001:* Taguchi proposed quality engineering for the 21st century [27]; *Technological Development in Machinery, Material and Machining* was published [28].

We can see that in most cases its difficult data analysis procedure stands out because it was founded on the design of experiments. However, investigating why Taguchi tackled the design of experiments, we can see that this is because rationalization and streamlining of experiments were essential for technological development; that is, they comprised management of technological development per se [29]. Therefore, without understanding the origin of the concept, we are mired in methodological difficulty.

The origin of the concept of quality engineering arises in nature, and because of this, the concept is considered difficult to understand. That is, although we can think something, we need to spend an enormous amount of energy to prove it concretely and to realize it practically. Quality engineering attempts to rationalize and streamline this cumbersome process, thereby enriching our lives in the time saved. There are a number of scholars who think of the idea abstractly, yet engineers are obligated to use it in a concrete manner. To achieve this, we always need to combine an idea and a methodology. However, since each reader can come to the book *Design of Experiments* only within his or her capability of understanding, many readers miss its overall concepts.

## 5.2. Conceptual Transition of the SN Ratio and Establishment of Quality Engineering

According to Masanobu Kawamura, ex-president of the Japanese Standards Association, who was a behind-the-scenes promoter of quality engineering, Genichi Taguchi often says something 10 years ahead of the natural course of development. And there is another reason that his ideas are sometimes obscure: Although developed extremely early, they are always evolving; thus, it is quite difficult to distinguish between old and new proposals. For example, the concept of the SN ratio in quality engineering appeared in Chapter 26 of Reference 4, published in 1958. Because this seemed to be based on the variance ratio of noises and effective elements, some people believe that it can be regarded as being completely different from the current SN ratio. However, its essence has not changed at all. Although it was devised a long time ago, it took a long time to be understood by many people and applied to many practical uses. Finally, mixed development of its concept and methodology made it difficult to comprehend.

Although publication of the *SN Ratio Manual* [7] in 1972 clarified the SN ratio in measurement, the idea that it is important to evaluate measurements based on the SN ratio in the measurement world, even in the case when true values are unknown, is still not comprehended, even by some measurement engineers today. This is because they focus on results instead of making an effort to understand their essence.

Since 1973, the SN ratio has most often been applied to design and machining. A typical example is evaluation of driving performance by Takeshi Inao, the ex-CEO of Isuzu Motors [30]. Initiated at Taguchi's proposal, this research dealt with changes in driving performance according to the characteristics of truck tires. By setting the rotational angle of a steering wheel, $M$ to a signal factor, they calculated the SN ratio using a linear equation between the rotational angle and turning radius when a truck's turning radius arrived at the state shown in Figure 5.1. Although we can take advantage of a zero-point proportional equation to calculate the SN ratio if this were analyzed today, up to 1987, linear equations were used in

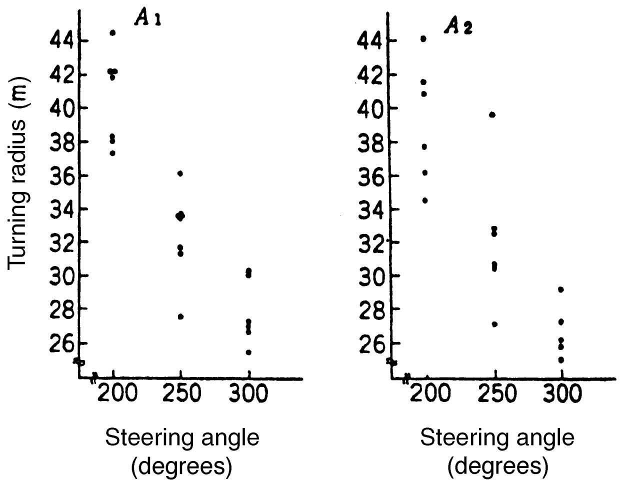



**Figure 5.1**
Relationship between steering angle and turning radius

the majority of SN ratio applications. In some cases the main effect of a signal factor when its true value was not known was analyzed using $S_M$ instead of $S_\beta$.

Although this Isuzu experiment is considered a monumental achievement in research on the dynamic SN ratio, shortly after this experiment, to obtain the Deming Prize, Isuzu stopped utilizing the quality engineering technique, because the panel of judges disliked the technique. It is well known that afterward, Isuzu became affiliated with General Motors. Some authors, including Soya Tokumaru [31, 32], harshly criticized this symbolic incident as doing harm to a specific company and to the Japanese concept of total quality control. In contrast, Tokumara highly praised the Taguchi method.

Since 1975, a correspondence course on the SN ratio has been available from the Japanese Standards Association. The primary field in which the SN ratio was utilized in Japan at that time was quality control; therefore, the course was targeted to metrology and quality control engineers. When Hiroshi Yano began to work at the National Research Laboratory of Metrology of the Agency of Industrial Science and Technology in the Ministry of International Trade and Industry (currently known as the National Research Laboratory of Metrology of the National Institute of Advanced Industrial Science and Technology in the Ministry of Economy, Trade and Industry), he attempted to introduce the SN ratio in the field of metrology. Yano studied under Genichi Taguchi as visiting researcher at the laboratory between 1972 and 1976 [33].

The SN ratio of formability was applied by Yano to the evaluation of plastic injection molding at that time and led to transformability in 1989 [34] after almost a 15-year lapse. On the other hand, adaptation to the cutting process led to the current evaluation of machining based on electric power [35]. This change took 20 years to accomplish.

Uses of the SN ratio before and after the 1970s was related to test, analysis, and measurement. Around 1975, when this was well established, quality engineering began to be applied to design and production engineering for the purpose of using dynamic characteristics. According to the latest classification, the SN ratio used for measurement is categorized as a passive dynamic SN ratio, and the ratio used for design and machining is seen as an active dynamic ratio. Using it as an active dynamic SN ratio, Yano attempted to apply quality engineering to plastic injection molding and cutting processes. Here's what he said [16]:

> For the SN ratio in plastic injection molding, we began our research by considering what to select as signal factors. As a result, setting holding pressure to the input signal and dimension to the output, we used the SN ratio expressed in a linear equation with dimensions of a formed product. Many achievements obtained by this method eventually led to proposing transformability of setting die dimensions to signals, which was considered a revolutionary change in 1989.
>
> As for a cutting process, we started to argue whether to select a linear or zero-point proportional equation by choosing the depth of cut as a signal and amount of cut as an output value. Finally, we failed to come to convince machining experts.

A basic understanding of quality engineering was decided by the publication of Reference 14 early in 1988. In particular, Volume 1 of the *Quality Engineering Series* contributed much to fostering the concept of quality engineering. However, this is a revised edition of the textbook used in the quality engineering seminars offered by the Japanese Standards Association.

*Quality Engineering for Technological Development* [17], published in 1994, a revised edition of "Introduction to Quality Engineering," which appeared in serial form in a technical journal, *Standardization and Quality Control*, posed a new problem after the Quality Engineering Series appeared. Its focus on semiconductor, electrical characteristics, chemical reactions, and the Mahalanobis–Taguchi system (MTS) especially pioneered a new phase of quality engineering.

At about that time, manufacturers of electric appliances, many of which are concentrated in the Kansai region in western Japan, began research using quality engineering. One piece of systematic research was carried out by Yano Laboratory of the University of Electro-Communications and Yoshishige Kanemoto of Clarion [25]. This fundamental research developed into the concept of selecting a direct-current pulse for an alternating-current circuit as a signal, and furthermore, frequency itself as output.

In the area of chemical reactions, Tosco and Sampo Chemical began experimenting on chlorella and bean sprouts; later, Toagosei and Tsumura & Co. announced research on use of the SN ratio in chemical reactions. It is not well known that at that time, Konica, under the guidance of Genichi Taguchi, led the way by evaluating the performance of photographic film using quality engineering. Because in chemical reactions an individual reaction cannot be quantified and only an overall reaction rate can be estimated, a logarithmic SN ratio based on the dynamic operating window method began to be used [24].

As transformability developed, the concept of a generic function SN ratio and a functional evaluation SN ratio, which are used to develop materials based on proportionality between load and deformation or masses in the water and air, spread in the late 1990s. Around 2000, more and more people began to acknowledge that the SN ratio plays a key role in the MTS.

## 5.3. On-line Quality Engineering and Loss Function

Around 1975, the study of expressing improvement effects using the loss function was heated up. Although the special research program subsidized by the Ministry of International Trade and Industry motivated corporations, their understanding of the study was not sufficient. Indeed, they had a strong interest in the concept per se but did not comprehend how to put the loss function to practical use. Even if they understood it, the concept of reducing consumer loss was difficult to understand in a corporate-oriented culture, positioning a company itself in the center of business. In those days, the idea that reduction of in-house defects would lead to quality improvement in terms of quality control was dominant in many industries, whereas the phrase *customer satisfaction* is commonly used now. Therefore, the technique of expressing quality through the loss function was considered only an idea.

An article about quality problems in color television sets manufactured by Sony, titled "Japanese Company in America," appeared in *Asahi Shimbun* on April 17, 1979. As illustrated in Figure 5.2, the fact that U.S. buyers preferred Sony products manufactured in Japan to those made in the United States, even if the design of the sets was exactly the same, gave some implications of the quality issue and proved the appropriateness of the quality engineering definition of quality; that is, the quality of a product should be measured not by an acceptance rate but by the deviation from a design target value.

The reason that the evaluation method based on the loss function strongly attracted those engineers who promoted quality engineering was that it could express technological improvements by quality losses or economic effects. Additionally, aggressive promotion of this concept by ASI (the American Supplier Institute) influenced Japan significantly. On the other hand, in Japan, the Metrology Management Association, supervised by the Ministry of International Trade and Industry, emphasized the loss function when they taught quality engineering. However, in the 1990s the loss function concept began to be recognized by design engineers. Although the amount of improvement, estimated to be $1 million, is not regarded as surprising among quality engineering experts, this amount was viewed as questionable by many at that time.

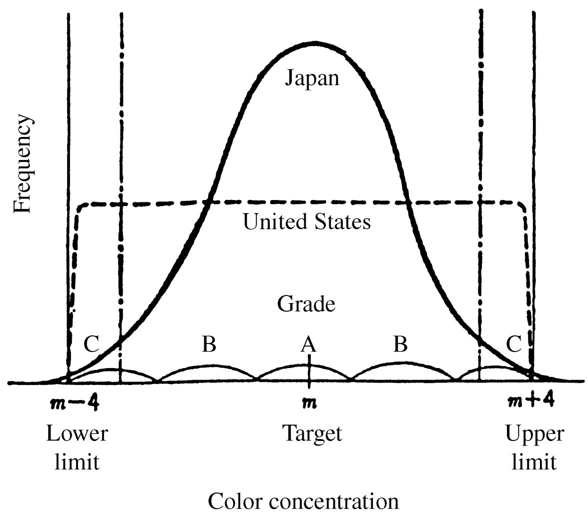



**Figure 5.2**
Quality characteristic distribution of Japanese and U.S. products

The original objective of the loss function is related to optimization of manufacturing process management and can be regarded as most significant. This field, called *On-line quality engineering,* was introduced earlier than off-line quality engineering, which had been studied since the 1960s as a successor of the design of experiments for manufacturing process management. The studies began with managerial problems in the manufacturing process at Fuji Film and were established through research on managerial issues regarding manufacturing processes at Toyota and Nippon Denso. As a consequence, in the late 1980s, on-line quality engineering came to be well known. In addition, after being introduced under the name *statistical process control* (SPC) in the United States, it was again recognized in Japan.

Because the initial managerial problems in manufacturing processes were complex, it was considered reasonable that many could not understand them completely [35]. Although this issue is closely related to Taguchi's overall achievements, the most essential idea is gradual improvement of the method itself after identifying the essence of any problems. In other words, a key to understanding the method is to define the range of applications through concrete results. This process of transition and development is regarded as the history of quality engineering. Therefore, quality engineering evolves continually and remains unfinished at all times.

On-line quality engineering has been applied to a wider range of fields since the latter half of the 1980s. However, the number of case studies involving on-line quality engineering is still much smaller than those related to off-line quality engineering. To reduce CEO costs, doubling of the production speed was proposed in the 1990s [36].

A major concept of on-line quality engineering is that we need only parameter study, with no experiments. Therefore, we proceed with analysis only by investigating current problems or through calculation. Based on these calculations, we can then grasp solutions to current problems. As a result, we can use calculations to study the possibility of doubling production speed. We can identify problems in a targeted manufacturing process and clarify problems to be solved technically. Yet because this concept is concerned heavily with the loss function, top management or supervisors who have considered the quality issues to focus on the number of in-process defects cannot easily understand the concept. Around the year 2000, Mazda began to tackle this problem positively [37].

## 5.4. SN Ratio in Machining

According to quality engineering guidelines—that an output characteristic, $y$, is proportional to an input signal, $M$—an experimental cutting process, reported in 1978, was grounded on the idea of proportionality of the amount of cut, $y$, with respect to the depth of cut, $M$ [38]. In those days, if the experimental results were not consistent with conventional technical knowledge, the experimental procedure was questioned; even if the results conformed with the knowledge, the new experimental methodology was not appreciated. As shown in Figure 5.3, because the mainstream calculation method was based on a linear equation, most analyses focused on a comparison of the linear and proportional equations.

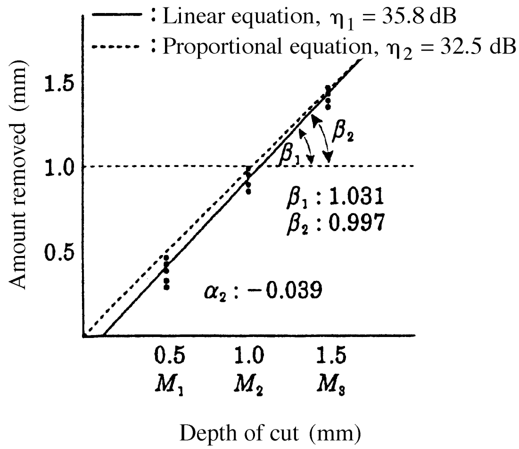



**Figure 5.3**
Depth of cut and amount removed

In 1981, once the subcommittee on the machining precision SN ratio was organized by Hidehiko Takeyama, the chairman, and Hiroshi Yano, the chief secretary, in the Japan Society for Seikigakkai (currently known as the Japan Society for Precision Engineering), research on the application of quality engineering to various machining technologies began to be conducted, primarily by local public research institutes.

These research results were reported in the research forum of the Japan Society for Seikigakkai and in the technical journals *Machine Technology,* published by Nikkan Kogyo Shimbun, and *Machine and Tool,* published by Kogyo Chosakai. Finally, a round-table talk titled "Expected Evaluation Method Based on SN Ratio Applicable to Design and Prototyping Such as Machine Tools" was reported in *Machine Technology* in August 1986 [11]. The participants were four well-known experts in each field: Hidehiko Takeyama (Tokyo University of Agriculture and Technology), Sadao Moritomo (Seiko Seiki), Katsumi Miyamoto (Tokyo Seimitsu), and Yoshito Uehara (Toshiba Tungaloy), together with Hiroshi Yano, whose job it was to explain quality engineering.

Following are the topics discussed by the round table:

1. SN ratio (for evaluation of signal and noise effects)
2. Error-ridden experiments (regarded as more reliable)
3. Importance of successful selection of control factors
4. New product development and design of experiments
5. Possible applicability to CAD systems
6. Effectiveness in evaluation of prototypes
7. Possible applicability of method to tools
8. High value of method when used properly
9. Significance of accumulation of data

Although the phrase *design of experiments* is used, all contents were sufficiently well understood. However, there were some questions about why it takes time for the SN ratio to be applied for practical uses.

Selecting depth of cut as input, the zero point becomes unclear. To clarify this, an experiment on electrode machining using the machining center was conducted by Sanjo Seiki in 1988. In this case, as illustrated in Figure 5.4, they chose dimensions indicated by the machining center as signal factors and machined dimensions as output. This concept is considered as the origin of transformability [39]. It was in 1987 when the zero-point proportionality displaced the linear equation, and thereafter, in the field of machining, the zero-point proportionality has been in common use.

In 1988 a study subcommittee of the Advanced Machining Tool Technology Promotion Association encouraged application of quality engineering to the mechanical engineering field [15], and a quality engineering project by the IMS in 1991 accelerated it further. When an experiment implemented by Kimihiro Wakabayashi of Fuji Xerox was published in the journal *Quality Engineering* in 1995 [19], Genichi Taguchi, the chairman of the judging group, advised them to calculate the relationships between time and electric power and between work and electric power. An experiment that reflected his advice was conducted at the University of Electro-Communication in 1996 [40], and later, Ishikawajima-Harima Heavy Industries [41] and Nachi-Fujikoshi Corp. [42] continued the experiment.

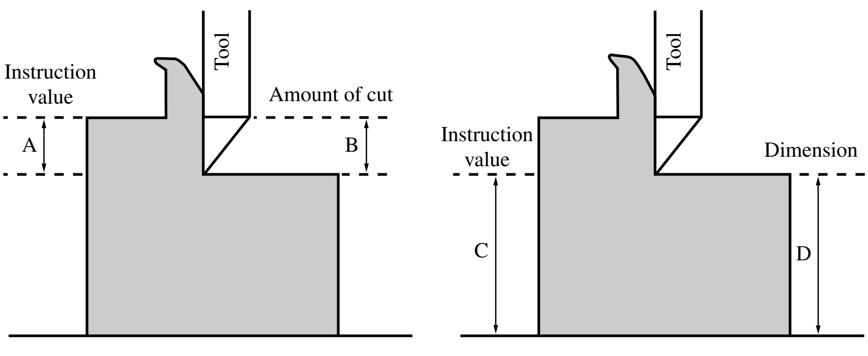
Setting electric power $y$ to output, and time $T$ and work $M$ to signal factors, we define the following as generic functions:

$$Y = \begin{cases} \beta_1 T & \beta_1 \text{ large} \quad (5.1) \\ \beta_z M & \beta_z \text{ small} \quad (5.2) \end{cases}$$

Since electric power is energy, considering that each equation is expressed in terms of energy, we take the square root of both sides of each equation. If $\beta_2$ decreases, we can obtain a great deal of work with a small amount of electric power. That is, we can improve energy efficiency. Converting into a relationship between $T$ and $M$, we obtain

$$M = (\beta_1/\beta_2)\,T \qquad (5.3)$$

As a result, the time efficiency can be improved. Looking at the relationship between $T$ and $Y$, we see that momentary electric power is high. This idea can be applied to a system that makes use of energy conversion.




(*a*) Cut by target amount of cut

(*b*) Cut up to target dimension

**Figure 5.4**
Depth and amount of cut (1978)

## 5.5. Evaluation Method Using Electric Power in Machining

Quality engineering advocates the invariable principle that "to get quality, don't measure quality." In fact, this idea is difficult to comprehend because the concept that "quality is everything" has been widespread. However, according to Taguchi, cost should be prioritized.

When the experiment on cutting was implemented at the University of Electro-Communications in 1996, good reproducibility was obtained using electric power evaluation, and quality characteristics were also improved. However, not everything went well from the beginning. What was regarded as a problem at first was fluctuation of electric power during idling. We barely succeeded in calibrating actual electric power by taking advantage of its average. Yet when a different machine was used in the next experiment, we could not obtain sufficient reproducibility. After reconsidering the data shown in Figures 5.5 to 5.7, we finally fixed the problem in 1998 [43].

In the meantime, since evaluation of electric power during idling was questioned due to poor reproducibility in an experiment conducted by Ishikawajima Harima Heavy Industries (IHI), IHI and Nachi-Fujikoshi Corp. undertook various studies. Among them was a new proposal of the concept of *on* and *off* functions offered by Taguchi [44]. In case of machining, the state of machining is regarded as an on function, whereas the state of idling is an off function.

However, in much of the research on machining, machining conditions and tools were selected as control factors. That is, from the standpoint of a user of a machine tool, machining conditions and tools can be chosen as control factors. Therefore, we needed to conduct research on a manufacturer of machine tools from the user's point of view. In 2000, Matsuura Machinery Corp. implemented parameter design of the main axis of a high-speed machining center. Although they had a problem with heat generated in the main axis turning at high speeds, they clarified that it was possible to reduce heat in the main axis only by evaluating electric power during idling [45]. This symbolized the invariable principle: "To get quality, don't measure quality."

There is a tendency to evaluate the machining process quite often, for example, as a method of measuring stress on a tool. Although we wished to do this based on our desire to explain a phenomenon, this method looks at a tool only in place of a machine. Taguchi insists that signal and noise factors are consumer conditions. If we relate this idea to the fact that the SN ratio is energy conversion, it is sufficient

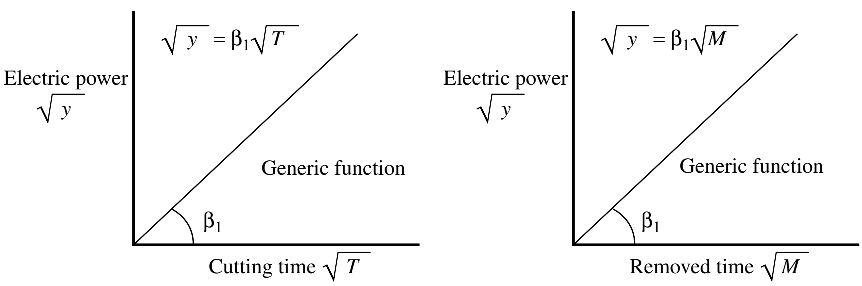



**Figure 5.5**
Relationship between instructive values and amount of cut (1980)

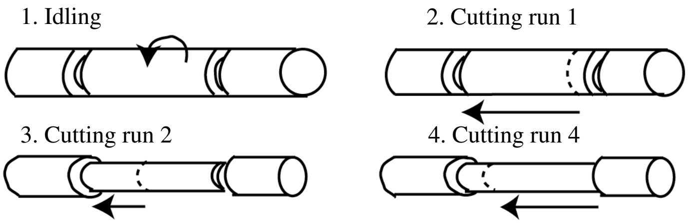



**Figure 5.6**
Evaluation by electric power

to evaluate only a result instead of a process. However, in the case of technological elements in lieu of final products, we face difficulties deciding what to do.

Yet from the viewpoint of original technological functions, evaluation of results is totally different. We have a strong interest in whether quality characteristics are improved or not when evaluated based on electric power. In this case, variability in dimensions and surface roughness of the machined product under optimal conditions are reduced to 1/4 and 1/1.3. That is, the principle "to get quality, don't measure quality" holds true. The fact that electric consumption is small for the amount of cut indicates that a tool cuts well and its life span will be prolonged. Therefore, we can dispense with a design life test.

This method of evaluating machining based on electric power rather than the dimensions of a product implies a new possibility. As mentioned earlier, this method is widely applicable not only to machining but also to almost all systems that hinge on energy conversion.

## 5.6. SN Ratio of Transformability

Although the dynamic SN ratio was commonly used in the 1980s for practical uses such as in design or machining areas, it was not a standardized practice, especially when in the late 1980s, the SN ratio was classified into dynamic and nondynamic characteristics. Smaller-the-better, nominal-the-best, and larger-the-better SN ratios were defined as nondynamic SN ratios. To standardize the idea of the SN ratio, we digressed considerably from the original objective of using the dynamic SN ratio. Since the nondynamic SN ratio was easily understood by statisticians, many statistical discussions took place. In fact, Kenzo Ueno of the quality engineering

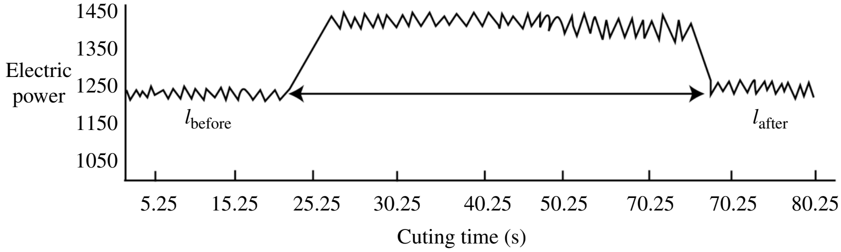



**Figure 5.7**
Power changes of cutting run 1

promotion department in the Nissan Technical Center prohibited the use of nondynamic SN ratios because of the power of dynamic SN ratios.

Study of the application of quality engineering to plastic injection molding began in the plastic study group of the Japan Society of Plastic Technology, led by Yano, in the latter half of the 1970s, and significant achievements were obtained regarding the dynamic SN ratio based on a linear equation or nominal-the-best SN ratio. Eventually, this activity led to JIS K-7109, *Rules of Dimensional Tolerances of a Plastic Part,* the first JIS related to quality engineering, in 1986.

Also, The National Research Laboratory of Metrology triggered the research and development of CAMPS (Computer-Aided Measurement and Process Design and Control System), which aimed to optimize production engineering and to design and manage production processes. Its first focus was plastic injection molding; however, later the focus changed to ceramic injection molding. Still, the study of dynamic SN ratios was insufficient [46].

In the Quality Engineering Seminar on plastic injection molding given by the Japan Society of Plastic Technology in March 1989, Genichi Taguchi proposed a new idea: that "the function in plastic injection molding is the relationship between the dimension of a die and the corresponding dimension of the product." Because of much difficulty measuring plastic dimensions in this case, this idea was not accepted immediately, but it had a great impact. This led to compilation of a book, *Technological Development of Transformability* [16].

Nevertheless, the common idea that each engineer's technical skill in designing a die is linked directly to the ability to forecast product shrinkage was prevalent in the field of plastic injection molding at that time, so the proposal of transformability provoked many plastic molding engineers, and eventually, the idea was criticized as a "pedant's nonsense." The SN ratio of transformability was applied to a broad range of other engineering fields, such as forming, photocopying, printing, and cutting. What was most important was that the discussion encouraged engineers to consider what the SN ratio was, or what its generic function was.

Because Genichi Taguchi regarded transformability not as a generic function but as an objective function, transformability in plastic injection molding evolved into a relationship between load and deformation of a product, or proportionality between masses in the air and water.

On a different note, about the time of the Great Hanshin Earthquake in 1995, the concept of SN ratio for shape retentivity was suggested. Although it should function well for cases such as earthquakes, no effective application has been reported to date.

## 5.7. SN Ratio in Electric Characteristics

When parameter design was proposed by Genichi Taguchi in the late 1970s, the initial example focused on the parameter design of the Wheatstone bridge, based on a nominal-the-best SN ratio. Therefore, the concept of parameter design is considered to have begun with electric characteristic simulation.

The first major achievement in Japanese parameter design was the book *Parameter Design for New Product Development,* edited by the Metrology Management Simplification Study Committee of the Metrology Management Association (chairman:

Genichi Taguchi; chief secretary: Hiroshi Yano) [10]. This book was initiated to collect examples of parameter design, most of which were characterized as applications of electric characteristic simulation by measurement instrument manufacturers. The complex-number example of Yokokawa Hewlette Packard transistor development, based on an $L_{108}$ orthogonal array, highly evaluated by Genichi Taguchi, was introduced in this book.

However, since the analysis of simulation was thought to be a commonplace method using nominal-the-best SN ratio with no excitement of using such an SN ratio, and regarded as mere application of simulation using the software existing in Japan, the topics of parameter design shifted from simulation to experimentation.

For these reasons, only a small number of examples focused on electric characteristics, whereas mechanical engineering examples accounted for the majority. However, this trend changed when parameter design was applied to semiconductors for the first time. Patterning of semiconductors started in the field of transformability. Although many Japanese companies kept this application extremely confidential and almost no examples were reported publicly, Sumitomo Electric Industries released their experimental result of patterning transformability because the company was a follower in the semiconductor industry.

Based on the idea that a generic function was essential in the 1990s, utilization of Ohm's law led to its application to electric characteristics. At first, in the semiconductor field, Sumitomo Electric Industries obtained a significant achievement by measuring electric characteristics in place of patterning transformability [47]. Next, Nachi-Fujikoshi succeeded in using a procedure to calculate voltage–current characteristics instead of observing soldering defects as a conventional metric. However, at first, these researchers did not mention the fact that a key to success is to utilize four-terminal circuits. It was later unveiled in other experimental reports [48].

Whereas the example of sensor welding studied by the University of Electro-Communications and IHI utilized electric characteristics in lieu of the original function, research on electric circuits themselves was begun by the University of Electro-Communications and Clarion. In the latter research, various types of experiments were attempted to evaluate the reproducibility of gains in the parameter design of a dc amplification circuit. Although a number of problems with the experimental method were identified successfully, inconsistency of a few decibels caused Genichi Taguchi dissatisfaction with the result, which led to a new method of utilization of pulse to evaluate ac circuits. From this study, Yoshishige Kanemoto of Clarion began to devote more time to research using frequency characteristics as the output. Indeed, it can be regarded as a follow-up to research on a nominal-the-best SN ratio in a ceramic oscillating circuit conducted by Sharp Corp. in 1995 [49]; it successfully clarified a formulated method of evaluating electric circuits [25].

Although Genichi Taguchi has made many new proposals, including applications of amplitude, frequency, and pulse and new circuits and research using simulation, up to the present time, few significant achievements based on his proposals have been reported. However, because the book *Technological Development in Electric and Electronic Engineering* was published in 2000 [25], research in this area can be expected to flourish.

## 5.8. Chemical Reaction and Pharmacy

In the chemical reaction area, quality engineering began to be applied in 1993 after Genichi Taguchi proposed the use of natural logarithms in the technical journal *Standardization and Quality Control*. Thereafter, this analysis procedure was formulated as the *dynamic operating window method*. This was subdivided into two methodologies, the *speed difference method* and the *speed ratio method* [24].

Since it is quite difficult to measure chemical reaction or cell division directly as a molecular-level reaction, we need to measure it on a scale such as a percentage or fraction. That is, instead of a generic function, an objective function is used. In reference to the relationship between time and the sensitivity curve, by taking a natural logarithm of the fraction and linearizing it, we can calculate a dynamic SN ratio.

This idea was also applied to the cultivation of bean sprouts and led to the achievement obtained by Fushimi Yoshino of Sampo Chemical [24]. Afterward, the use of natural logarithms attracted many people and was also applied to cases where a functional curve saturates, as in a capacitor [25].

The method of using natural logarithms is not limited to chemical reactions. However, Toagosei and Tsumura & Co. accomplished significant results by applying the technique to chemical synthesis and particle granulation, respectively. Toagosei's synthesis is an example of the speed difference method [51], and Tsumura's granulation is based on the speed ratio method [52]. Both of them are aimed at stabilizing the reaction speed using two curves of main and side reactions without noise factors in the studies. In the future, setting of noise factors may become a subject of study.

For the pharmaceutical industry, Genichi Taguchi proposed a method using cells looking at main and side effects [44]; however, no significant example has been reported thus far. Yet for the evaluation of medical efficacy, the results of experiments on the permeability of ointment into human skin and medical efficacy of an herbal medicine using mice have been reported [24]. Although government regulations allow the use of statistical methods, including using more animals for performing such experiments, the new method enabled researchers to eliminate this science-oriented research attitude and attain productive achievements, according to Genichi Taguchi.

Especially for the latter case, where it had been regarded as impossible to obtain approval of a new medicine in the field of herbal medicine, by taking advantage of parameter design, they proved its medical efficacy and obtained official approval. This event is considered as epoch-making in that it succeeded in advancing the phase of experimentation on medical efficacy [53]. In other words, quality engineering demonstrated its effectiveness in the field of herbal medicine in a situation that Western medical analysis could not deal with.

## 5.9. Development of the Mahalanobis–Taguchi System

Since the quality engineering methodology developed by Genichi Taguchi utilizes conventional statistical methods in a different manner, at first the method was quite often misunderstood and criticized as being an existing statistical method.

Similarly, the SN ratio was criticized as mere ANOVA (analysis of variance), and the zero-point proportional equation was misunderstood as regression analysis. In addition, the orthogonal array was considered to be an already existing method. However, even though the orthogonal array existed at that time, the concept of the $L_{18}$ orthogonal array was new and had a different objective.

In addition, the MTS method was misunderstood as discriminant analysis because it takes advantage of the Mahalanobis distance. Whereas discriminant analysis deals with the distinction between two different groups, the MTS method takes the position that there is a single group, but distances are compared by deviations from the base space, which is the origin. This is identical to the concept of a zero-point proportional equation defining a zero point and unit amount, and it can be regarded as a problem of SN ratio and parameter design in a multidimensional space.

The origin of the MTS method dates back to the research on reliability improvement of medical checkups undertaken by Tatusji Kanetaka in 1987. Despite the fact that Kanetaka attained a significant number of results, the new method did not spread to technological fields because its application had only a limited scope in medicine. After Genichi Taguchi proposed application of the MTS method to a fire alarm in the technical journal *Quality Engineering* in 1996 [51], an experiment at the University of Electro-Communications fueled its application to technological fields.

The essential idea in the MTS method is to create a base space. In the case of a disease, we create a space of "being healthy," and in case of fire, a space of "no fire." Since this concept is regarded as a paradox or as mere rhetoric, it often cannot be understood, and additionally, there existed no data for the base space. That is, even if there are data for the disease or fire, we have no other choice but to prepare or seek the data as to "being healthy" or "no fire" to create a base space. This is the uniqueness and difficulty of the MTS method.

Further, it was difficult to set a signal factor level to express the degree of disease or the degree of fire from a specialized standpoint. The SN ratio was dealt with as a larger-the-better characteristic in most cases because it was difficult to set such a signal. For the study of setup of signals in the 1970s, there were similar problems when the SN ratio was proposed. In particular, in the case of measurement engineering for the case when true values are unknown, many attempts were made to set up signals; the MTS method still has a similar serious technical problem.

In any case, there is no doubt that MTS brought about numerous achievements through a growing number of applications to technological and medical fields in the late 1990s. However, when we apply the method to practical uses, we sometimes face troubles with multiple correlation caused by calculation of the inverse matrix of coefficients or the problems caused by the order of items in selecting them when Schmidt's orthogonal expansion is used. To solve this, Genichi Taguchi has suggested bridging MTS methods for the tenty-first century. This application is regarded as our future task [27].

The MTS software released by Oken, based on the software developed based on the University of Electro-Communication's research on a fire alarm, is considered easy to use and has, in fact, contributed greatly to application of the MTS method by taking advantage of Genichi Taguchi's hands-on coaching.

## 5.10. Application of Simulation

Quality engineering relies heavily on Genichi Taguchi's creativity and powerful coaching style in all aspects, including Design of experiments in the 1960s, the SN ratio in the 1970s, the Taguchi method in the 1980s, and the transformability and generic function in the 1990s. The fact that his achievements have been supported by various groups that have applied his ideas to practical uses should not go unnoted. What should we do next in the transitional period? One anticipated issue is innovation of the MTS method; another is a new proposal for the SN ratio in simulation. One typical example of this is described below. It shows how Genichi Taguchi's proposal has developed.

As discussed thus far, simulation was used in some cases of use of the SN ratio in the 1970s. However, since the nominal-the-best SN ratio was generally used (reflecting the fact that many cases of simulation are based on a linear relationship), most engineers did not have a strong interest in calculating SN ratios in simulation. Therefore, application of the SN ratio to simulation gradually became excluded from the mainstream in quality engineering. Yet in the Judging Subcommittee in 2000, Genichi Taguchi mapped out a new policy of vigorous evaluation of parameter design in simulation, as there existed few good examples of simulation at that time.

When the simulation session was added in the 8th Quality Engineering Research Symposium in 2000, it was noted that many simulation experts avoided using parameter design in simulation because results obtained through simulation often disagreed with actual results. In addition, it was thought that with regard to the finite element method, if a "finer mesh" is used (meaning that if more combinations are studied), if many more meshes are created in order to match the simulation results with the actual results, an enormous amount of time would be needed and would thus discourage the experts to use the method.

In response to this concern, Genichi Taguchi vehemently argued that because simulation results do not need to agree with actual results and we should stress only stability (evaluated by the SN ratio) and also argued that it is not necessary to increase the fineness of a net (more knots by more combinations) in a study.

This argument was posed in the Taguchi Method Symposium held by ASI in November 2000. In fact, the nonlinearity simulation on a switch implemented by ITT Cannon triggered Genichi Taguchi's new proposal, which was presented at the Quality Engineering Symposium given by the Central Japan Quality Management Association in Nagoya in the same month. In this symposium, a new method of calculating the SN ratio was suggested, with the practical example of "Optimization of Dimensional Parameters in Mechanical Design" studied by the Oki Electric Industry [26].

More specifically, the following was argued as a general discussion [28]: In case of a conventional simulation, on assumption of no nonlinearity effect against signal factors, nominal-the-best SN ratios have been applicable. However, at the ASI fall symposium in 2000, an example regarding a nonlinear simulation was presented which triggered a new approach. The calculations are as follows:

Signal factor:
Design target of signal output:

$$M_1^* \quad M_2^* \quad \cdots \quad M_k^*$$

$$m_1 \quad m_2 \quad \cdots \quad m_k$$

Output under standard condition ($N_0$): Output under $N_0$ as signal:

$$\begin{matrix} Y_{01} & Y_{02} & \cdots & Y_{0k} \\ M_1 & M_2 & \cdots & M_k \end{matrix}$$

Output value under noise condition:

$$Y_{11} \quad y_{12} \quad \cdots \quad Y_{1k}$$

$N_1$ (negative side), $N_2$ (positive side)

$$Y_{21} \; Y_{22} \cdots Y_{2k}$$

Total variation:

$$S_T = y_{11}^2 + y_{12}^2 + \cdots + y_{2k}^2 \qquad (f = 2k) \tag{5.4}$$

Variation of proportional terms:

$$S_\beta = \frac{(L_1 + L_2)^2}{2r} \qquad (f = 1) \tag{5.5}$$

Effective divider:

$$\begin{aligned} r &= M_1^2 + M_2^2 + \cdots + M_k^2 \\ &= y_{01}^2 + y_{02}^2 + \cdots + y_{0k}^2 \end{aligned} \tag{5.6}$$

Linear equations:

$$\begin{aligned} L_1 &= M_1 y_{11} + M_2 y_{12} + \cdots + M_k y_{1k} \\ L_2 &= M_1 y_{21} + M_2 y_{22} + \cdots + M_k y_{2k} \end{aligned} \tag{5.7}$$

Variation of differences of proportional terms:

$$S_{N\beta} = \frac{(L_1 - L_2)^2}{2r} \qquad (f = 1) \tag{5.8}$$

Error variation:

$$S_e = S_T - S_\beta - S_{N\beta} \qquad (f = 2k - 2) \tag{5.9}$$

Error variance:

$$V_e = \frac{S_e}{2(k - 1)} \tag{5.10}$$

Total noise variance:

$$V_N = \frac{S_{N\beta} + S_e}{2k - 1} \tag{5.11}$$

SN ratio:

$$\eta = 10 \log \frac{(1/2r)\ (S_\beta - V_e)}{V_N} \tag{5.12}$$

Sensitivity (proportional term):

$$\beta = \frac{M_1^* m_1 + M_2^* m_2 + \cdots + M_k^* m_k}{M_1^{*2} + M_2^{*2} + \cdots + M_k^{*2}} \tag{5.13}$$

First, we select control factor levels to maximize the SN ratio; that is, we make an adjustment to match the sensitivity with the target.

The standard SN ratio, which we renamed the SN ratio based on this idea, was proposed in the chapter on reliability testing in the third edition of *Design of Experiments,* Vol. 2 [4]. As the SN ratio of the relationship between on–off output and input in the quality engineering of a digital system, this idea is explained on the following pages. [See the calculations preceding equation (5.4) and the explanation that follows.]

The standardized error rate is

$$\rho_0 = \frac{1}{1 + \sqrt{[(1/p) - 1][(1/q) - 1]}} \tag{5.14}$$

Assuming the standardized error rate above, we obtain Table 5.1 as the input/output table. The contribution for this case is called the *standard degree of contribution,* which is calculated as follows:

$$\begin{aligned} \rho_0 &= [(1 - p_0)^2 - p_0^2]^2 \\ &= (1 - 2p_0)^2 \end{aligned} \tag{5.15}$$

By taking into account noise's contribution of $1 - \rho_0$ based on the result above, we can calculate the standardized SN ratio $\eta_0$ as follows:

$$\begin{aligned} \eta_0 &= 10 \log \frac{\rho_0}{1 - \rho_0} \\ &= -10 \log \left( \frac{1}{\rho_0} - 1 \right) \end{aligned} \tag{5.16}$$

This SN ratio, calculated in the standard error rate after leveling, is called the *standard SN ratio.*

The standard SN ratio above is constructed with on–off (or digital) data. The new SN ratio, which is the same concept but is constructed with continuous variables, is still called the standard SN ratio. Genichi Taguchi considers the standard

**Table 5.1**
Standardized input/output table

| | Output | | |
|---|---|---|---|
| **Input** | **0** | **1** | **Total** |
| 0 | $1 - p_0$ | $p_0$ | 1 |
| 1 | $p_0$ | $1 - p_0$ | 1 |
| Total | 1 | 1 | 2 |

SN ratio with continuous variables to be the quality engineering of the twenty-first century.

The key is to stabilize variability first, then tune the output to the target. This is the philosophy of two-stage optimization: that the new standard SN ratio attempts to perform thoroughly. This idea is regarded as the basis of quality engineering and a clue to the future development of quality engineering. That is, it will be taken advantage of in all fields.

We can see that each of various problems considered in the initial phase of the design of experiments is being investigated through the succeeding research process. In actuality, we are so occupied in working on practical studies through evolution of the design of experiments that we do not have enough time to deliberate each of the issues that was originally brought out. Therefore, even if each problem posed at each time is seen as standing alone, all of them are interrelated continuously.

## 5.11. Summary

Most of Genichi Taguchi's achievements have been announced in the technical journal *Standardization and Quality Control,* published by the Japanese Standards Association, which is not a commercial magazine but an organ of the foundation. The journal contents are often related to standardization (JIS) and quality control or statistical methods. Thus, even if a certain report focused on quality engineering, its title ended with the words "for quality management" until the 1980s, which meant that Taguchi's achievements appeared in the organ only because it was in the field of quality control. In the late 1980s the uniqueness of quality engineering as distinct from "quality control" was finally accepted. Since 1986, the journal regularly features quality engineering in a special article and has sometimes covered activities in the United States. The insight shown by the Japanese Standards Association, which continued to use his reports as articles, cannot be overlooked.

In general, these reports were regarded as academic achievements that were supposed to appear in academic journals. The reason that his reports were instead, systematized in *Standardization and Quality Management* is because each academic discipline in Japan is usually focused on achievements in a specialized field. Therefore, the universal concept of quality engineering did not fit a journal dealing with a specific discipline.

Quality engineering as formed in the foregoing context took full shape after 1990 and led to establishment of the Quality Engineering Society. The theme of quality engineering in the 1990s was its proposal of a new perspective in each technological field, which began with a mention in the publication *Quality Engineering for Technological Development* [17].

When we look back to the history of quality engineering, we notice that a new proposal is initiated every time an achievement is accomplished. The field is not static. So what is the newest proposal? This is what quality engineering positions as *functionality evaluation* or *technological development methodology* as a managerial issue. Unfortunately, one problem is that the majority of those who attempt to comprehend and promote quality engineering are not strategic but tactical people. Thus, the functionality evaluation has often been seen not as a strategy but as a tactic.

To alter this perspective, *technological development using simulation* has been suggested as a strategy for the twenty-first century. In addition, *functionality evaluation in trading* was proposed for businesses. This has already been published using the term *evaluation technique for optimization* and is under discussion as a topic regarding ISO or JIS standardization of quality engineering.

Standardization of quality engineering, a project founded on a budget of $700,000, was begun as research on the optimization design and evaluation technique of quality engineering in the Global Standard Creation Research and Development Program supported by the Ministry of International Trade and Industry. Although this project accomplished a number of significant results through technological research that commonly would not be attempted, Genichi Taguchi's R&D methodology was judged not to be standardized, and subsequently, a standardization draft called *functionality evaluation,* limited to business trading, was written up. In addition, a group was dispatched to the United States to promote quality engineering. Unfortunately, it has been difficult to understand for engineers familiar with reliability or design life test in conventional quality control. Since quality engineering is not a concept lodged in traditional statistical methods, it cannot be acknowledged easily by statistical experts who are assigned to be responsible for standardization. Quality engineering has offered a ubiquitous methodology of technological development centering on parameter design. By using the evaluation scale of the SN ratio, we can easily assess the technical possibilities. Nevertheless, determination of a SN ratio is dependent on specialized or individual technology. This fact brings up another difficulty with quality engineering.

The essence of this problem is that to determine the evaluation scale of an SN ratio or generic function requires technological creativity. In short, a generic function is not a ready-made product but a custom-made invention. Therefore, if we obtain poor reproducibility of gain in parameter design, we have no other choice but to reconsider a new measurement characteristics. Furthermore, if this idea is extended, we come back to Genichi Taguchi's insistence that "we should discover the failure of experiments as soon as possible," typified by an experiment conducted by IHI in which, despite the fact that masses of drills were damaged in the experiment, an efficient machining process was attained under optimal conditions. However, this experimental process is not easy for many engineers to accept.

Between the 1960s and 1970s, Genichi Taguchi's achievements were widely accepted by automobile manufacturers and related companies, especially in the Nagoya area. Based on the judgment that his ideas would not become more widespread in Japan, his accomplishments at Bell Labs were "imported" back from the United States to Japan and had a considerable impact. As quite often happens, a certain thing that has been evaluated in Japan to only a limited degree comes to be highly valued once it succeeds in the United States. This is regarded as a traditional Japanese custom, which some people believe derived from ancient history, as when Japan introduced Chinese culture.

Genichi Taguchi's main activity to promote his methodology has been lectures and case studies of examples in the Quality Control Research Group (QCRG) of the Central Japan Quality Control Association and the QCRG of the Japanese Standards Association. Whereas the former was begun in 1951 and held primarily in the Nagoya area, the latter originated in 1963 and continued around Tokyo.

Through an annual symposium held at an alternative location, the technical exchange of both associations was facilitated.

In the research forum, lectures based on Genichi Taguchi's books were given, and practical applications were reportedly discussed by participants from many corporations. In 1989, the QCRG was renamed the Quality Engineering Research Group (QRG). In line with these research forums, the two associations held a seminar on the design of experiments (a 20-day course) led by Genichi Taguchi, which is considered to have contributed a great deal to promoting the design of experiments and quality engineering. This corresponds to the expert course offered by ASI in the United States.

Although the design of experiments seminar gained an extremely favorable reception in the Japanese Standards Association, Genichi Taguchi changed the content of the seminar as the design of experiments developed into quality engineering. Although it was not always well understood by many, it is still highly valued.

After his success at Bell Labs renewed public awareness of quality engineering, its evolution not only gave rise to enthusiastic believers but also kept many from shying away from it, due to its being overly complicated. Its successful application by Fuji Xerox triggered technological competition based on quality engineering among Japanese photocopy manufacturers. The peak of this is recognized to be the panel discussion "Competition on Quality Engineering Applications Among Copy Machine and Printer Manufacturers" at the 7th Annual Symposium of the Quality engineering Society in 1999.

As with the standard SN ratio in simulation, quality engineering has many methods that are not taken advantage of fully. The Technical Committee of the Quality Engineering Society has planned to sponsor seminars on important problems since 2001.

Now we close with two remarkable points. One is *management by total results,* an idea created by Genichi Taguchi that any achievement can be calculated based on the extent of loss given to "downstream" or following departments as the "degree of trouble" when the tasks of each department are interrelated. In fact, it seems that this idea, developed by Genichi Taguchi in the late 1960s, was put forward too early. However, now is considered to be an excellent time to make the most of this idea, as more people have become receptive to it.

The other point related to *experimental regression analysis,* which is related to the analysis of business data. Although this supplements regression analysis from a methodological viewpoint, it is considered a good example of encouraging engineers to be aware of a way of thinking grounded on technologies. Unfortunately, technical experts do not make full use of this method; however, it is hoped that it will be utilized more widely in the future.

Since the Taguchi methods are effective to elucidate phenomena as well as to improve technological analyses, it is expected to take much longer for these methods to move further into the scientific world from the technological field.

It is roughly estimated that the number of engineers conducting quality engineering–related experiments is several tens of times the current 2000 members in the Quality Engineering Society. We hope the trend will continue. In Chapter 6 we cover the introduction of Taguchi methods in the United States.

## References


1. Genichi Taguchi, 1999. *My Way of Thinking*. Tokyo: Keizaikai.
2. Genichi Taguchi, 1965. Issue of adjustment. *Standardization and Quality Management,* Vol. 18, No. p. 10.
3. Hitoshi Kume, Akira Takeuchi and Genichi Taguchi, 1986. QC by Taguchi method. *Quality,* Vol. 16, No. 2.
4. Genichi Taguchi, 1957–1958. *Design of Experiments,* Vols. 1 and 2. Tokyo: Maruzen.
5. Shigeru Mizuno, Genichi Taguchi, Shin Miura, et al., 1959. Production plant experiments based on orthogonal array. *Quality Management,* Vol. 10, No. 9.
6. Genichi Taguchi, 1966. *Statistical Analysis*. Tokyo: Maruzen.
7. Shozo Konishi, 1972. *SN Ratio Manual.* Tokyo: Japanese Standards Association.
8. Genichi Taguchi, et al., 1975. *Evaluation and Management of Measurement*. Tokyo: Japanese Standards Association.
9. L. E. Katz, and M. S. Phadake. 1985. Macro-quality with macro-money. *Record.*
10. Genichi Taguchi, 1984. *Parameter Design for New Product Development*. Tokyo: Japanese Standards Association.
11. Hidehiko Takeyama, 1987. Evaluation of SN ratio in machining. *Machine Technology,* Vol. 3, No. 9.
12. Hiroshi Yano, 1995. *Introduction to Quality Engineering*. Tokyo: Japanese Standards Association.
13. Genichi Taguchi, 1985–1986. Design of experiments for quality engineering. *Precision Machine,* Vol. 51, No. 4 to Vol. 52, No. 3.
14. Genichi Taguchi, 1988–1990. *Quality Engineering Series,* Vols. 1 to 7. Tokyo: Japanese Standards Association.
15. Study Subcommittee for Quality Design System in Next-Generation Production System, 1989. *Research on Production Machining System Using Analytic Evaluation, Measurement, and Inspection*. Advanced Machining Tool Technology Promotion Association.
16. Ikuo Baba, 1992. *Technological Development of Transformability*. Tokyo: Japanese Standards Association.
17. Genichi Taguchi, 1994. *Quality Engineering for Technological Development*. Tokyo: Japanese Standards Association.
18. Genichi Taguchi, 1993. Inaugural speech as a chairman. *Quality Engineering,* Vol. 1, No. 1.
19. Kimihiro Wakabayashi, Yoshio Suzuki, et al., 1995. Study of precision machining by MEEC/IP cutting. *Quality Engineering,* Vol. 3, No. 6.
20. Genichi Taguchi, 1996. What does quality engineering think? *Machine Technology,* Vol. 44, No. 1.
21. Katsuichiro Hata, 1997. New JIS and ISO based on quality engineering concept. *Standardization and Quality Management,* Vol. 50, No. 5.
22. Genichi Taguchi, 1998. Memorial lecture: quality engineering technology for 21st century. *Quality Engineering,* Vol. 6, No. 4.
23. Taguchi Award Planning Subcommittee. 1999. Prescription of Quality Engineering Society Taguchi Award (draft). *Quality Engineering,* Vol. 7, No. 4.
24. Akimasa Kume, 1999. *Quality Engineering in Chemistry, Pharmacy, and Biology*. Tokyo: Japanese Standards Association.

25. Kazuhiko Hara, 2000. *Technological Development in Electric and Electronic Engineering*. Tokyko: Japanese Standards Association.
26. Genichi Taguchi, 2001. Robust design by simulation: standard SN ratio. *Quality engineering,* Vol. 9, No. 2.
27. Genichi Taguchi, 2001. Quality engineering for the 21st century. *Collection of Research Papers for the 91st Quality Engineering Research Forum.*
28. Hiroshi Yano, 2001. *Technological Development in Machinery, Material, and Machining*. Tokyo: Japanese Standards Association.
29. Genichi Taguchi, and Hiroshi Yano. 1994. *Management of Quality Engineering*. Tokyo: Japanese Standards Association.
30. Takeshi Inao, 1978. Vehicle drivability evaluation based on SN ratio. *Design of Experiments Symposium '78*. Tokyo: Japanese Standards Association.
31. Soya Tokumaru, 1999. *Ups and Downs of Japanese-Style Business Administration*. Tokyo: Diamond.
32. Soya Tokumaru, 2001. *Novel: Deming Prize*. Tokyo: Toyo Keizai Inc.
33. Taguchi Genichi, Tokyo: Coronasha.
34. Hiroshi Yano, 1976. Technical trial for evaluation of measurement and moldability in plastic injection molding. *Plastics,* Vol. 22, No. 1.
35. Genichi Taguchi, 1967. *Process Adjustment*. Tokyo: Japanese Standards Association.
36. Genichi Taguchi, 1995. Reduce CEO's cost. *Standardization and Quality Management,* Vol. 48, No. 6.
37. Teizo Toishige, and Hiroshi Yano, 1978. Consideration of cutting error evaluation by dynamic SN ratio. *Collection of Lectures at Seikigakkai Spring Forum.*
38. Keiko Yamamura, and Tsukako Kuroiwa, 1990. Parameter design of electrode machining using machining center. *Plastics,* Vol. 36, No. 12.
39. Kazuhito, Takahashi, Hiroshi Yano, et al, 1997. Study of dynamic SN Ratio in Cutting," *Quality Engineering,* Vol. 5, No. 3.
40. Kenji Fujioto, Kiyoshi Fujikake, et al., 1998. Optimization of Ti high-speed cutting. *Quality Engineering Research Forum.*
41. Masaki Toda, Shinichi Kazashi, et al., 1999. Research on technological development and productivity improvement of drilling by machining energy. *Quality Engineering,* Vol. 7, No. 1.
42. Kazuhito Takahashi, Hiroshi Yano, et al., 1999. Optimization of cutting material using electric power. *Quality Engineering,* Vol. 8, No. 1.
43. Genichi Taguchi, 2000. *Robust Design and Functionality Evaluation*. Tokyo: Japanese Standards Association.
44. Tsuguo Tamamura, and Hiroshi Yano, 2001. Research on functionality evaluation of spindle. *Quality Engineering,* Vol. 8, No. 3.
45. Hiroshi Yano, 1987. Precision machining and metrology for plastics. *Polybile,* Vol. 24, No. 7.
46. Susumu Sakano, 1994. *Technological Development of Semiconductor Manufacturing*. Tokyo: Japanese Standards Association.
47. Genichi Taguchi, 1994. Issues surrounding quality engineering (1). *Quality Engineering,* Vol. 2, No. 3.
48. Koya Yano, 2001. *Quality Engineering,* Vol. 9, No. 3.
49. Genichi Taguchi, 1995. Total evaluation and SN ratio using multi-dimensional information, and Design of multi-dimensional machining system. *Quality Engineering,* Vol. 3, No. 1.

50. Tatusji Kanetaka, 1997. Medical checkup judgment by applying Mahalanobis distance. *Quality Engineering,* Vol. 5, No. 2.
51. Takashi Kamoshita, Kazuto Tabata, Hiroshi Yano, et al., 1996. Optimization of multidimensional information system using multi-dimensional information: case of fire alarm. *Quality Engineering,* Vol. 4, No. 3.
52. Genichi Taguchi, 2001. Robust design by simulation: standard SN ratio. *Quality Engineering,* Vol. 9, No. 2.
53. Genichi Taguchi, 2000. *Evaluation Technique for Optimal Design: Standardization and World-wide Promotion of Quality Engineering.* Tokyo: Japanese Standards Association.