2 Management for Quality Engineering

2.1. Management's Role in Research and Development

Planning Strategies

The principal job of top management in an R&D or engineering department is planning strategy for technological development, classified into four general groupings. These are not specialized technologies but generic approaches that contribute to a wide range of technical fields in the long term.

Sun Tzu on the Art of War [1] is regarded as strategy, whereas technology represents tactics. Each specialized technology offers a concrete solution (design or means). New products or technologies are concrete results obtained through engineering research. However, since new products can survive only a few years without continuous creation of new products and technologies, we can be defeated by competitors. Conceptualization and selection of systems are creative jobs often conducted by engineers. Because determining parameters is only routine design work, it should be both rationalized and computerized.

Unlike the truth, technology is not in pursuit of what lasts eternally. However, strategic technology should be used as widely and as long as possible. R&D investment is supposed to be ongoing continually to ensure the success of a corporation. As a part of corporate strategy, some percentage of total sales should be invested on a continuing basis. Through technical activities, people in charge of R&D need to develop new products and technologies that are competitive enough to maintain a company and help it to grow. To date, Japanese financial groups have invested very little in R&D organizations. Although Mitsubishi Research Institute and Nomura Research Institute have research departments, little research has been conducted on R&D itself.

A key task of an R&D department is to rationalize and streamline a broad range of technical activities directed toward the development of new products and technologies. A means that can often be used in most fields of technological development is technological strategy per se, called *generic technology*.

One of the principal generic technologies is the streamlining of measurement and evaluation technologies. The reason is not that development engineers do not have good ideas but that they need to use most development time and resources for experimenting, prototyping, and testing to evaluate their ideas. A key rationalization of experiments and tests, including simulation, is to develop a product that functions well under conditions of mass production or various markets (including targeted design life) and causes little pollution and few difficulties when small-scale research is being conducted or test pieces are being used. In fact, it does not mean that engineers are not creative. However, they do not attempt to proceed to the next ideas until their current ideas have clearly failed. Then, rational evaluation, especially the accurate prediction of ideas, is required.

Strategy planning and personnel affairs are management roles in R&D. Top management is charged with planning business strategies, determining types of products to be produced, and allocating managers and budgets of engineering departments to design products (R&D and design departments). Quite often they proceed with their duties without knowing whether or not their decisions are correct; however, they need to take responsibility for their results in business competition in accordance with a balance sheet or profit and loss statement.

Design of Product Quality: Objective Function

Manufacturers plan products in parallel with variations in those products. If possible, they attempt to offer whatever customers wish to purchase: in other words, made-to-order products. Toyota is said to be able to deliver a car to a customer within 20 days after receipt of an order, with numerous variations in models, appearance, or navigation system. For typical models, they are prepared to deliver several variations; however, it takes time to respond to millions of variations. To achieve this, a production engineering department ought to design production processes for the effective production of high-mix, low-volume products, which can be considered rational processes.

On the other hand, there are products whose functions only are important: for example, invisible parts, units, or subsystems. They need to be improved with regard to their functions only.

Selection of Systems: Concepts

Engineers are regarded as specialists who offer systems or concepts with objective functions. All means of achieving such goals are artificial. Because of their artificiality, systems and concepts can be used exclusively only within a certain period protected by patents. From the quality engineering viewpoint, we believe that the more complex systems are, the better they become. For example, a transistor was originally a device invented for amplification. Yet, due to its simplicity, a transistor itself cannot reduce variability. As a result, an amplifier put into practical use in a circuit, called an *op-amp,* is 20 times more complicated a circuit than that of a transistor.

As addressed earlier, a key issue relates to what rationalization of design and development is used to improve the following two functionalities: (1) design and development focusing on an objective function under standard conditions and (2) design and evaluation of robustness to keep a function invariable over a full period of use under various conditions in the market. To improve these functionalities, as many parameters (design constants) should be changed by designers as possible. More linear and complex systems can bring greater improvement. Figure 2.1 exemplifies transistor oscillator design by Hewlett-Packard engineers, who in choosing the design parameters for a transistor oscillator selected the circuit shown in the figure. This example is regarded as a functional design by simulation based on conceptualization. Through an L_{108} orthogonal array consisting of 38 control factors, impedance stability was studied.

Top management is also responsible for guiding each project manager in an engineering department to implement research and development efficiently. One practical means is to encourage each manager to create as complicated a system as possible. In fact, Figure 2.1 includes a vast number of control factors. Because a complex system contains a simpler one, we can bring a target function to an ideal one.

The approach discussed so far was introduced in a technical journal, *Nikkei Mechanical,* on February 19, 1996 [2]. An abstract of this article follows.

> "LIMDOW (Light Intensity Modulation Direct Overwrite) Disk," developed by Tetsuo Hosokawa, chief engineer of the Business Development Department, Development Division, Nikon Corp., together with Hitachi Maxell, is a typical example that has successfully escaped from a vicious cycle of tune-up by taking advantage of the Taguchi Method. LIMDOW is a next-generation magneto-optical disk (MO) that can be both read and rewritten. Its writing speed is twice as fast as a conventional one because we

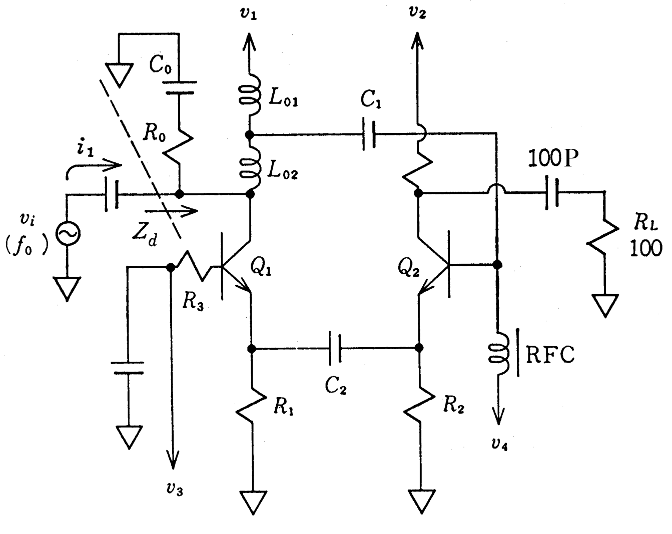

Figure 2.1
Transistor oscillator

> can directly rewrite new data on an old record. For a conventional MO, old data needs to be erased before new ones are recorded.
>
> To achieve this, we have to form at least six and at most nine magnetic layers on a LIMDOW disk, whereas only one layer is formed on a conventional one. Because of unstable production processes, Nikon faced a number of technical difficulties. There were approximately ten design parameters to form only a single layer in process; therefore, they had to adjust over ninety parameters in total for nine layers.
>
> According to Hosokawa, this problem with parameters was so complex that they almost lost track of the direction in development. In addition, interaction between each layer happens once a multi-layer structure is designed. That is, if a certain optimal manufacturing condition is changed, other conditions are accordingly varied. Moreover, since optimal conditions depended greatly on which evaluation characteristics for a product were chosen, a whole development department fell into chaos.
>
> Six years passed with prototyping and experimentation repeated. Despite six years spent, they could not obtain a satisfactory functional prototype. To break this deadlock, they introduced the Taguchi Method. Three years afterward, they stabilized forming processes, and finally in 1995, they found a prospect for mass production. A LIMDOW-type MO disk is already established as an international standard of the International Standardization Organization (ISO) and being developed by other major disk manufacturers. Nikon Corp. was the first company to succeed in mass production and is still monopolizing the market.

Currently, photographic film comprises about 20 layers. Since some of the layers could be unnecessary, engineers at photographic filmmakers need to evaluate which layers are required as control factors, using parameter design. A development approach whereby a complicated system is attempted after a simple one fails does not lead to effective optimal design of robustness but instead, results in technical improvement by tolerance adjustment. Designers' philosophy at Hewlett-Packard can help your understanding (see Figure 2.1). In quality engineering, a system to be selected by specialized engineers should be more complicated because we have the flexibility to adjust functional robustness to an objective function due to many control factors (design constants that can be selected at the designers' discretion).

2.2. Evaluation of Functionality

Technological development is different from general personnel management in that unlike human beings, new products and technologies or hardware and software cannot operate voluntarily. In the development and design phases, an R&D department needs to predict accurately how many problems a product (including software) they have developed will cause in the marketplace throughtout its life span. There are various kinds of uses expected in the marketplace, some of which cannot be predicted. In the chemical industry, how to evaluate whether a product developed in a laboratory can be produced on a large scale without adjustment (in most cases, in chemical reaction time) is quite important. A key issue in technological development is to predict functionality "downstream," in contrast to "upstream," in the development stage.

Up to this point, where we are dealing with technical procedures in technological development, each engineer's ability is highly respected and final evaluation of a product is assessed by other departments, such as reliability engineering or quality assurance. This procedure is similar to that of financial accounting in terms of checking up only on final results. However, it cannot function well as technological management. Each engineer is required to provide not only predictability of results but functionality (reliability) in the development stage.

The reason that the consequence approach fails in technological management is that in most technological research, engineers are limited in the following ways:

1. Since they aim to research as simple a system for an objective function as possible, they often fail to improve functional stability (robustness) in a market that involves various conditions, and to perform tune-ups for an objective function under standard conditions. This is because they are not trained to become creative enough to select a complicated system in the first place. For example, *Parameter Design for New Product Development* [3] shows complex systems designed by Hewlett-Packard. Because, in general, circuit elements (especially integrated-circuit and large-scale integrated elements) are quite cheap, to develop a larger-scale, more complex circuit helps to improve functionality; at the same time, encouraging developers to do so is considered a job for management.
2. Researching specialized characteristics in engineering books does not help us avoid technical problems in the marketplace involving numerous unknown factors. Since there are only two types of factors, *signal factors* (without them, a product becomes useless) and *noise factors* (the smaller they become, the better), few researchers have not utilized an SN ratio that measures functional robustness while maintaining signal factor effects. Therefore, after technological development or design research is complete, conventional evaluation methods have not been able to predict unexpected problems caused by various conditions regarding mass production and customer use, which are different from those in the laboratories. We discuss functionality evaluation in Chapter 3.
3. Since quality and cost are predicted according to economic evaluation in both the design and production stages, they are not well balanced.

It is a essential managerial task in engineering departments to change the foregoing paradigms (schemes) of thinking used by engineers. In Europe and the United States, a change in thinking, termed a *paradigm shift,* is attained in two ways. For all three above, cases, we train research and development engineers to change their way of thinking. Especially for case 2, by altering functional test procedures in a design department, we lead engineers to use SN ratios for functional robustness assessment. In this section we explain case 1 and 2.

Functionality (Performance) Evaluation, Signals, and Noise

For both hardware and software, to evaluate how well a product functions in the marketplace (when designed or developed), we need to consider signal factors, which represent consumers' use conditions, and noise (error) factors for both hardware and software. Signal factors are of two types, active and passive, and noise also comprises two types, indicative and true. An *active signal factor* is a variable that a person uses actively and repeatedly: for example, stepping down on an accelerator pedal. On the other hand, a *passive signal factor* is a sensed or observed value that is used passively for processing of measurement or judgment. In an actual system, there are a number of these factors. For an entire range of signal, we should predict how well a function works. That is, by clarifying an ideal function for a signal we need to evaluate how close to the ideal function the signal factor effects can come.

A *true noise factor* is a factor whose noise effects should be smaller: for instance, an environmental condition or deterioration in a life span. If initial signal factor effects of a product never change under standard conditions or over any length of time, we say that it has good functionality or robust design. *Indicative factors* whose effects are regarded as not vital are selected to prove that a product can function well under any of them. For example, although an automobile's performance does not need to be the same at low, middle, and high speeds, it should be satisfactory at all of the speeds. An indicative factor is a noise condition that is used to evaluate a product's performance for each condition in a large environment.

We detail each field of functionality evaluation in Chapter 3.

2.3. Design Process

Tools for Designing

Among tools (procedures, techniques) to streamline design research are the following:

1. *Generic tools:* computer, orthogonal arrray
2. *Specialized tools:* finite element method software, circuit calculation method software
3. *Measurement standard*

We describe an *orthogonal array* as a tool specialized for quality engineering. Although many other tools are also important related to quality engineering, they play an essential role in information processing in all engineering fields, not just in quality engineering. An orthogonal array is regarded as special in the quality engineering field because it not only deals with difference equation calculation but also evaluates reproducibility of functionality for "downstream" conditions.

Evaluation of Reproducibility

To evaluate functionality under conditions of mass production or various applications by means of test pieces, downsized prototypes, or limited flexibilities (a life test should be completed in less than one day, a noise test is limited to only two conditions) in a laboratory, signals and noises expected to occur in the market, as discussed above, should be taken into account.

However, by changing design constants called *control factors*, which are not conditions of use but parameters that can freely be altered by designers (including selection of both systems and parameter levels), designers optimize a system. Even if we take advantage of functionality evaluation, if signal factors, noises, and measurement characteristics are selected improperly, optimal conditions are sometimes not determined. Whether optimal conditions can be determined depends on the evaluation of reproducibility in the downstream (conditions regarding mass production or various uses in the market). Therefore, in the development phase, development engineers should design parameters using an orthogonal array to assess reproducibility. Or at the completion point of development, other evaluation departments, as a management group, should assess functionality using benchmarking techniques. The former approach is desirable; however, the latter is expected to bring a paradigm shift that stimulates designers to use SN ratios.

From a quality engineering viewpoint, a field that derives formulas or equations to explain target output characteristics, including reliability, is not considered engineering but physics. This is because any equation does not include economic factors, no matter how well it predicts the result. Physics deals with creating theories and formulas to account for natural phenomena. These theories are scientifically quite important, however, they are not related to designing products that are artificial. Since engineers design products or production processes that do not exist in nature, they are allowed exclusive use of their own inventions. Truth cannot be accepted as a patent because it is ubiquitous. Design is judged based on market factors such as cost and quality or productivity when used by customers. Productivity discussed here is productivity from a *user's* perspective. If a product of a certain manufacturer is much cheaper and has many fewer failures and much less pollution in each market segment than in others, it can increase its own market share. Good market productivity means that a product not only has good quality under standard conditions but also low production costs. That is, manufacturers that have good market productivity can sell at lower prices products of better technical quality (fewer defects, lower running cost, or lower social costs, such as pollution).

A key issue is whether or not we can predict and improve production cost or technical quality in the market prior to mass production or shipping. Market productivity, including product quality, is a way for a corporation to make a profit. Means for improving market productivity include design and manufacturing. Can we predict such market productivity accurately in the design and development phase? To predict market productivity, in addition to the marketability of a product, production cost and functionality must be forecast. This forecast is conducted through design evaluation. Although design is evaluated after development has been completed, in order to pursue optimal design, it should also be evaluated in the development stage when design can still be changed flexibly. Therefore, we need to find optimal design under laboratory conditions (e.g., using test pieces, small-scale studies, limited test conditions). We should evaluate whether factor effects hold true under downstream conditions (e.g., actual products, large-scale production processes; conditions of use, including various product lives). This is regarded as an issue of reproducibility in the downstream.

For product design to have reproducibility in downstream, evaluation characteristics need to be scrutinized as well as signals and noises. To make optimal design become optimal downstream, we should (1) realize that all conditions of use in the marketplace belong to either signals and noises, or do not; (2) determine levels of signals and noises; and (3) select characteristics to calculate rational SN ratios. In short, the use of rational SN ratios is a key factor. Thus, the reason that only the main effects of control factors are assigned to an orthogonal array is to determine whether they have additivity for SN ratios.

2.4. Automated Process Management

The first Industrial Revolution relieved humans of much physical labor by mechanizing machining operations in manufacturing processes. Currently, the major jobs of operators are production control, such as preparation of raw material, transportation, and fixturing of in-process products; machine setup and quality control, such as machining diagnosis and control; and inspection. Rationalization and mechanization of management operations are keys in today's second Industrial Revolution.

To rationalize and automate management operations, we are urged to establish theoretical economic fundamentals for them. Reference 4 interprets basic formulas and applications of daily management jobs in on-line departments such as manufacturing. Its distinguishing point from other guidelines is that the theory rests on system design and economic calculation.

Manufacturing departments are responsible for productivity, including cost. There are seven approaches to this [4]. The contents are explained in detail in Chapters 23 through 25.

1. *Quantitative quality evaluation of a shipped product.* Since defective products are not to be shipped and because that does not affect consumers, defect problems are not quality issues but cost issues.
2. *Product quality standard that is important in manufacturing.* By detailing how to determine tolerances, we show ways not only to estimate significance quantitatively when quality should come close to an ideal or target value but also ways to determine tolerances in negotiation or contracts. A distinctive feature is a new way of selecting safety factors, which has not been well defined. See JIS Z-8403 [5], which details how to determine standards.
3. *Feedback control in process. Process control* checks product characteristics or process conditions at a certain interval of time. If the values are within a limit, it determines whether or not to continue production; conversely, if they are beyond a limit, process conditions are adjusted. Chapters 3 to 5 of Reference 4 detail optimal system design for feedback control in a machining process. Refer to Chapter 23 through 25 for more details. This method hinges on economic system design that aims to balance checkup and adjustment cost and the economic quality level of a shipped product. Chapter 5 of Reference 4 covers calibration system design of measurement errors, that is, an assessment of the optimal number of operators.
4. *Process maintenance design.* Chapters 6 to 8 of Reference 4 offer ways to design process management when we can obtain only qualitative values, such as soldering characteristics instead of quantitative values, or when we can perform checkups only by inspecting gauges in lieu of management-designed gauges whose shapes are matched to products. To emphasize preventive maintenance during processing (preventive quality control), basic formulas and various applications, including preventive maintenance methods, are elucidated.
5. *Feedforward control.* In feedback control in process, we investigate the characteristics of a product and return it to its process. *Feedforward control* is a method of adjusting final characteristics to target values by changing process conditions. For example, in manufacturing film or iron, after the gelatin or ore received is inspected, optimal treatments or reaction conditions corresponding to those raw materials are selected for production. Feedforward control methods according to environment or adaptive control is detailed in Chapter 9 of Reference 4.
6. *Design of inspection systems.* For each product, quality characteristics are measured, their differences to target values are adjusted, and if they cannot be adjusted, each product is discarded. Although this procedure is considered

inspection in a broader sense, unlike approaches 3, 4, and 5, each product is inspected in this procedure. See Chapter 10 of Reference 4.

7. *Maintenance system design for a shipped product.* We should manage systems rationally in manufacturing, telecommunication, and traffic for products and services. When products and services will be produced, maintenance system design for the production system is crucial. In fact, availability management systems in production processes belong in this category.

These control, management, and maintenance systems are included in management activities based on information fed back. Currently, frontline operators are in charge of process management. Details of management design are discussed in Reference 4.

2.5. Diagnosis to Prevent Recall Problems

❒ Example

When we visited a Rolls-Royce helicopter engine plant in 1975, we saw that several-minute bench tests for all engines were being run, as well as life tests for every 25 engines. Since the annual engine production volume at that time was approximately 1000, they ran the life test approximately once a week. The life test took 160 hours to run, which was equivalent to the time before the first overhaul, and cost $25,000. If the test frequency could be reduced from every 25 engines to every 50, an annual reduction of $500,000 in the cost of inspections would be achieved.

We were asked whether the life test might be changed to every 50 engines. When I asked why they conducted the life test, they answered that they wished to find unexpected failures. That is, this is failure for unknown reasons, as discussed at the end of Chapter 1. Since it was almost impossible to investigate quality characteristics for each of thousands of parts, they substituted a life test as a simpler method. Because they could not prevent problems due to unknown items, inspection was the only solution. If inspection found defects and failures, human lives would not be lost.

To find such a serious problem that an engine stops is an example of technical management using function limits. In this case, a quality assurance department could be responsible for inspection because this inspection checks only whether or not an engine stops in the life test. We asked them for the following three parameters:

A: loss when a product does not function
B: inspection cost
$\bar{u}$: mean failure interval

Loss when a product does not function could be regarded as plant loss when an engine stops before its first overhaul. In this case we selected an engine replacement cost of about $300,000. Because the life test was conducted once a week and took almost a week to complete (this is called *time lag*), in the meantime a certain number of engines were mounted on various helicopters. However, since the life test at a plant can detect problems much faster than customers in the market can, we did not consider problems of loss of life due to crashes.

As noted earlier, the inspection expense is $25,000 and the mean failure interval (including failures both in the marketplace and at a plant), $\bar{u}$ was estimated to be "once in a few years." For the latter, we judged that they had one failure for every 2500 engines, and so set $\bar{u}$ to 2500 units. (Even if parameters deviate from actual values, they do not have any significant impact on inspection design.) For $\bar{u} = 2500$, we can calculate the optimal inspection interval using the equation that follows. The proof of this equation is given in Chapter 6 of Reference 4. For the sake of convenience, as a monetary unit, $100 is chosen here.

$$\begin{aligned} n &= \sqrt{\frac{2\bar{u}B}{A}} \\ &= \sqrt{\frac{(2) \times (2500) \times (250)}{3000}} \\ &\approx 20.4 \text{ engines} \end{aligned} \tag{2.1}$$

This happens to be consistent with their inspection frequency. For a failure occurring once in three years, a life test should be done weekly. We were extremely impressed by their method, fostered through long-time experience.

We answered that the current frequency was best and that if it were lowered to every 50, the company would lose more. We added that if they had certain evidence that the incidence declined from once in two or three years to once in a decade, they could conduct the life test only once for every 50 engines.

In fact, if a failure happens once in a decade, the mean failure interval $\bar{u} = 10{,}000$ units:

$$\begin{aligned} n &= \sqrt{\frac{(2)(100)(250)}{3000}} \\ &= 41 \text{ engines} \end{aligned} \tag{2.2}$$

This number has less than a 20% difference from 50 units; therefore, we can select $n = 50$.

On the other hand, when we keep the current $\bar{u}$ unchanged and alter n from 25 to 50, we will experience cost increases. Primarily, in case of $n = 25$, loss L can be calculated as follows:

$$\begin{aligned} L &= \frac{B}{n} + \frac{n+1}{2}\frac{A}{\bar{u}} + \frac{lA}{\bar{u}} \\ &= \frac{250}{25} + \left(\frac{25+1}{2}\right)\left(\frac{3000}{2500}\right) + \frac{(25)(3000)}{2500} \\ &= 10 + 15.6 + 30.0 \\ &= 55.6 \text{ cents } (\times\$100) \end{aligned} \tag{2.3}$$

Then, total annual cost, multiplied by an annual production volume of 1000, amounts to \$5,560,000.

Similarly, in case of $n = 50$, L is computed as follows:

$$\begin{aligned} L &= \frac{250}{25} + \left(\frac{50+1}{2}\right)\left(\frac{3000}{2500}\right) + \frac{(25)(3000)}{2500} \\ &= 5 + 30.6 + 30.0 \\ &= 65.6 \text{ cents} \qquad (2.4) \end{aligned}$$

Thus, total annual cost amounts to \$6,560,000. As a consequence, the company will suffer another \$1 million loss.

Based on long-time technical experience, they had balanced inspection cost and the cost of problems following sale of the product.

System Design for Recall Prevention

Occasionally, problems create a sensation. This is because, unlike Rolls-Royce, some manufacturers have a management system that cannot detect in-house failures. A quality assurance department can take responsibility for recall due to unknown items. If there is no quality assurance department, a quality control section in a manufacturing department should take responsibility.

❒ Example

For one particular product, failures leading to recall are supposed to occur only once a decade or once a century. Suppose that a manufacturer producing 1 billion units with 600 product types yearly experiences eight recalls in a year. Its mean failure interval $\overline{u}$ is

$$\begin{aligned} \overline{u} &= \frac{\text{total annual production volume}}{\text{annual number of failures}} \\ &= \frac{1{,}000{,}000{,}000}{8} \\ &= 125{,}000{,}000 \text{ units} \qquad (2.5) \end{aligned}$$

This is equivalent to *mean time between recalls* if no life test is conducted.

Whereas $\overline{u}$ is calculated for all products, parameters of A and B are computed for each product. For example, a certain product has an annual production volume of 1.2 million units and is sold at a price of \$4. In addition, a life test for it costs \$50 per unit and takes one week. In sum, A = \$4 and B = \$50. Given that mean failure interval $\overline{u}$ is equal to the value in equation (2.5),

$$n = \sqrt{\frac{2\overline{u}B}{A}}$$

$$= \sqrt{\frac{(2)(125{,}000{,}000)(50)}{4}}$$

$$\approx 56{,}000 \text{ units} \tag{2.6}$$

Now by taking into account the annual production volume of 1.2 million and assuming that there are 48 weeks in a year, we need to produce the following number of products weekly:

$$\frac{1{,}200{,}000}{48} = 25{,}000 \tag{2.7}$$

Therefore, 56,000 units in (2.6) means that the life test is conducted once every other week. The mean failure interval of 125,000,000 indicates that a failure occurs almost once in

$$\frac{125{,}000{,}000}{1{,}200{,}000} = 104 \text{ years} \tag{2.8}$$

In short, even if a failure of a certain product takes place only once a century, we should test the product biweekly.

What happens if we cease to run such a life test? In this case, after a defect is detected when a product is used, it is recalled. "Inspection by user" costs nothing. However, in general, there should be a time lag of a few months until detection. Now supposing it to be about two months and nine weeks, the, time lag l is

$$l = (25{,}000)(9)$$

$$= 225{,}0000 \text{ units} \tag{2.9}$$

Although, in most cases, loss A for each defective product after shipping is larger that that when a defect is detected in-house, we suppose that both are equal. The reasoning behind this is that A will not become so large on average because we can take appropriate technical measures to prevent a larger-scale problem in the marketplace immediately after one or more defective products are found in the plant.

If we wait until failures turn up in the marketplace, $B = 0$ and $n = 1$ because consumers check all products; this can be regarded as screening or 100% inspection. Based on product recall, loss L_0 is

$$L_0 = \frac{B}{n} + \frac{n+1}{2}\frac{A}{\overline{u}} + \frac{lA}{\overline{u}} \tag{2.10}$$

Substituting $n = 1$, $B = 0$, $A = \$4$, $l = 225{,}000$ units, and $\overline{u} = 125{,}000{,}000$ units into (2.11), we obtain

$$L_0 = \frac{0}{1} + \left(\frac{1+1}{2}\right)\left(\frac{4}{125{,}000{,}000}\right) + \frac{(225{,}000)(400)}{125{,}000{,}000}$$

$$= 0.0072 \text{ cent} \tag{2.11}$$

$$(0.0072)(1{,}200{,}000) = \$864 \qquad (2.12)$$

If we conduct no inspection, we suffer an annual loss of $8640 from recalls.

On the other hand, loss L when we run a life test once every two weeks is computed when we use $n = 50{,}000$ units, $B = \$50$, $A = \$4$, $l = 25{,}000$ units, and $\bar{u} = 125{,}000{,}000$ units:

$$\begin{aligned} L &= \frac{50}{50{,}000} + \left(\frac{50+1}{2}\right)\left(\frac{4}{125{,}000{,}000}\right) + \frac{(25{,}000)(4)}{125{,}000{,}000} \\ &= 0.001 + 0.0008 + 0.0008 \\ &= 0.0026 \text{ cent} \end{aligned} \qquad (2.13)$$

For an annual production volume of 1.2 million, the annual total loss is $3120:

$$(0.0026)(1{,}200{,}000) = \$3120 \qquad (2.14)$$

Comparing this with (2.12), we can reduce total cost by

$$8640 - 3120 = \$5520 \qquad (2.15)$$

If we can expect this amount of gain in all 600 models as compared to the case of no life test, we can save

$$(5520)(600) = \$3{,}312{,}000 \qquad (2.16)$$

That is, $3.3 million can be saved annually.

In this case we assume that cost A for the case of recall is equal to loss A, the cost for a defective product detected in-house. In most cases, this assumption holds true. On the other hand, once a defective product is shipped, if the product threatens human life or enormous loss of property, the loss should be increased, for example, to $2 million per product. However, no matter how many products are defective, we need to take measures. Thus, we assume that only one product puts human life at risk.

If the sum of other product costs is equal to A, for its original value of $4, the average of A should be increased by

$$\frac{2{,}000{,}000}{225{,}000} = \$8.89 \qquad (2.17)$$

Defining loss A in the case of recall as A_0, we have

$$A_0 = 8.89 + 4 = \$12.89 \qquad (2.18)$$

As for the value of a life test, only loss in the case of no life test is increased. Putting $A_0 = \$12.89$ into A of equation (2.10), the loss L_0 is calculated as to be 0.0232 cent. Comparing this loss with the loss using a life test, $L = 0.0026$ cent, the loss increases by

$$0.0232 - 0.0026 = 0.0206 \text{ cent} \qquad (2.19)$$

This is equivalent to an annual loss of

$$(0.0206)(1{,}200{,}000) = \$24{,}720 \qquad (2.20)$$

Therefore, unlike A when a defect is detected in-house, A_0 in the case of no life test (in general, a test only to check functions) is a loss for each defective product recalled.

Functions of the Quality Assurance Department

We propose the following two items as functions of a quality assurance department: (1) to test functions of a product (benchmarking test) in terms of design quality, and (2) to conduct inspection to prevent pollution and recall in terms of manufacturing quality. A design quality test is a functional test for environment or deterioration, more specifically, a test based on the dynamic SN ratio. Originally a design department is responsible for this test; however, they do not usually test the functions of parts purchased from outside suppliers. Therefore, a quality assurance department should implement a functional test for an objective function to assist a purchasing department. A quality assurance department ought to take full responsibility for both items 1 and 2. When unexpected problems occur in the marketplace, a quality assurance department takes full responsibility in terms of design quality, and when a product is recalled, so does the quality control department. Regarding item 2, it is more desirable to use SN ratios than to conduct life tests.

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