International Journal of Reliability and Applications
Vol. 2, No. 3, pp. 161-187, 2001

Quality, Product Quality, and Market Share Increase: A Perspective for Management Decisions

Dongsu Ryu *
Quality and Reliability Laboratory
Daewoo Electronics Co., Ltd, Incheon, Korea

Abstract. Starting with the meaning of the word *quality*, diverse concepts connoted by the term are examined. Instead of a bathtub curve, the desirable shape of a failure rate covering the entire life of a good product, which might be called hockey-stick line, is introduced. From the *hockey-stick line* and the definition of reliability, two measurements are extracted. The terms reliability, failure rate, product life, and durability are explained. From the customer's standpoint, the concept of *product quality* is classified in five factors, according to related technology: performance, reliability, conformance to specifications, customer perception, and fundamentals advantage. The correlation of the five factors for a first-class product is discussed. Since the market share of a company is determined as the competition result of its *product value*, defined as product quality and price, the market share increase is derived mathematically from the increment of product value. The market share increase, ΔS, can be calculated from the present market share, S, and the oriented relative value increment of new product, R, to the current product in the same company for the same market target: $\Delta S = S(1-S)\cdot R/(1+S\cdot R)$. Finally, the importance of separating warranty cost from the profit equation for the durables is explained.

Key Words : *quality, c-quality, reliability, failure, durability, r-reliability, bathtub curve, hockey-stick line, product quality, five factors, customer perception, fundamentals advantage, product value, oriented relative value increment, market share increase.*

1. INTRODUCTION

Quality improvement is a major objective of every business. Every CEO and director understands quality uniquely, since the concept of quality is confusing to both managers and scholars. Therefore, activities to improve the quality of products differ from person to person and company to company.

* *E-mail address : dsryu@ web.dwe.co.kr*

There is an important difference between quality in a narrow sense and reliability. The reason why reliability defects or failure occur clarifies this distinction. Redefining the concepts related to quality and connecting them to the related technology can help CEOs and directors improve the quality of their products.

As we know, a high quality product might nevertheless not prevail in the market. To assess quality in an effort to increase sales, the concept of *product quality* should be considered alongside conventional notions of quality(Schnaars(1991)).

Harvard professor D. Garvin wrote an article in 1987 that examines eight dimensions of product quality(Garvin(1987)), but Garvin might realize that managers would experience difficulties in trying to use his classification to improve product quality. Here, Garvin's dimensions have been rearranged and reduced to four factors to make the approach easier. A fifth factor has been added.

Improving product quality will contribute to increased market share. An equation is presented here on market share increase due to the increment of product value, which can be defined as the product quality and the price of a product(Gale(1994)) . We also propose the separation of costs before market release, with warranty costs after selling. This is because warranty costs will be time dependently related to the reliability of the product after selling.

Understanding these concepts and applying these equations to business activities so CEOs and managers can simply calculate their market share increase and estimate the business profit in advance and the results makes them take appropriate actions.

2. THE CONCEPT OF QUALITY

2.1 The difference between quality and reliability

The broad concept of quality includes reliability. This confuses many people, not least because in order to understand reliability properly, it is frequently necessary to understand complicated mathematics.

To narrow down the difference between quality and reliability, let's think of quality defects and reliability defects negatively. Quality defects, in a narrow sense, refer to deficient products or components at present, particularly deficient parts or an incorrectly assembled set. Quality defects are inspected and screened out by *comparison* with standard *specifications* that have already been confirmed at the time of the release of component drawings and assembly specifications. Therefore, quality is expressed with percentages. And reliability defects generally mean *failures* that might occur in the *future*, inside a product that has been working well so far. Therefore, reliability must be regarded as a ratio connected to units of time. The unit of reliability is the inverse of time.

Clearly, the concepts of quality in a narrow sense and reliability have different definitions and dimensions. We can call this quality, as we usually understand it, the *conformance quality*, and reliability the *future quality*. (Afterwards, conformance quality refers to quality in a narrow sense and is abbreviated to c-quality.)

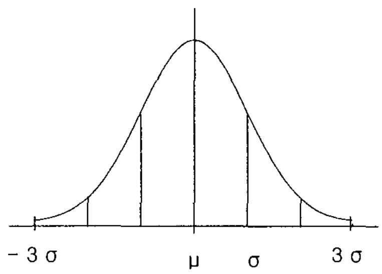
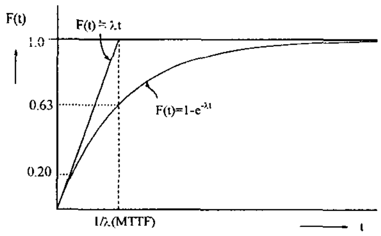
C-quality is frequently evaluated through the normal distribution and c-quality defects are usually annotated in percentages, or parts per million (ppm) that exceed both the upper and lower tolerance limits of a certain specification. Reliability is mainly analyzed through the exponential distribution and the representative index of reliability is expressed as percentage per hour, or annual failure rate.

If a product is carefully well designed and manufactured, the failure rate of the product is proportional to the time period till acceptable life to consumers, including on and off time by them after unpacking the product. The failure rate of a certain product lot, homogeneously reliable, has the following equation within product life(Ryu(1999)):

1 %/month = 12 %/year,

0.1 %/month = 1.2 %/year = 12 %/10 years.

This proportionality is suitable below about a 20 percent cumulative failure rate. Frequently the mean time to failure (MTTF) is used as a reliability index; but this is misleading, because the cumulative failure rate at the MTTF reaches to 63 percent failure. Cumulative failure rates of over 20 percent can be accepted in statistical analysis, but from the standpoint of making power brands in business it is too high, and therefore meaningless. Furthermore, to compare and assess business results, annual failure rates provide a better reliability index. Figure 1 summarizes the concepts of c-quality and reliability.

	Conformance-quality Defect	**Reliability Defect**
Concept	No-conformance to specification at present	Failure in the future
Dimension	None	1/hour
Unit	Percent ppm	Percent/year (Annual failure rate) Fit (1× 10^{-9}/hr)
Probability Function	Normal distribution $f(x)=\frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{(x-\mu)^2}{2\sigma^2}}$ 	Exponential distribution $*\ F(t)=1-R(t)=1-e^{-\lambda t}$ $\fallingdotseq \lambda t$ 

※ λt becomes small, the accumulated failure rate, F(t), will be proportional to time and then equals λt . In a practical sense, the approximation formula is adequate to cumulative F(t)< 0.2.

Figure 1. Conformance-quality and Reliability

The U.S. periodical **Consumer Reports** publishes the repair history of products, as determined through questionnaires discussing the reliability of that product. The figures in bar charts in their repair histories are calculated as the proportion of *repair and serious problem* cases to the quantity of products sold in the unit time (in this reference case, five years(Consumer Union(1998))). This rate can be divided by the total use years to provide a unit of measure. This becomes the annual after-sales service (AS) rate. Various products work anywhere from one to twelve months, so the working period can be assumed to be an average of six months—with the condition that the monthly product sales quantities are constant. Therefore, the annual AS rate is approximately half of the annual failure rate; conversely, the annual failure rate is twice the annual AS rate.

2.2 Why does failure occur?

As discussed above, the ambiguous term quality includes the concept of reliability. Let's consider the core concept of reliability. What is failure? Failure occurs when the materials in the components of the product are too weak to endure the applied stress, and/or when the stresses on the components are unexpectedly too great for the materials, as shown in Figure 2(Evans and Evans(2001)). The components might be broken due to repetitive stress during a given period as well. Deficient materials can suddenly break after a certain time in spite of receiving the rated stress. And good materials can also weaken gradually and fracture because of strength degradation with time. Polymers, like rubber, can degrade after simply being placed outside without protection under changing climates, as we saw in the accident of the Challenger spacecraft in 1986.

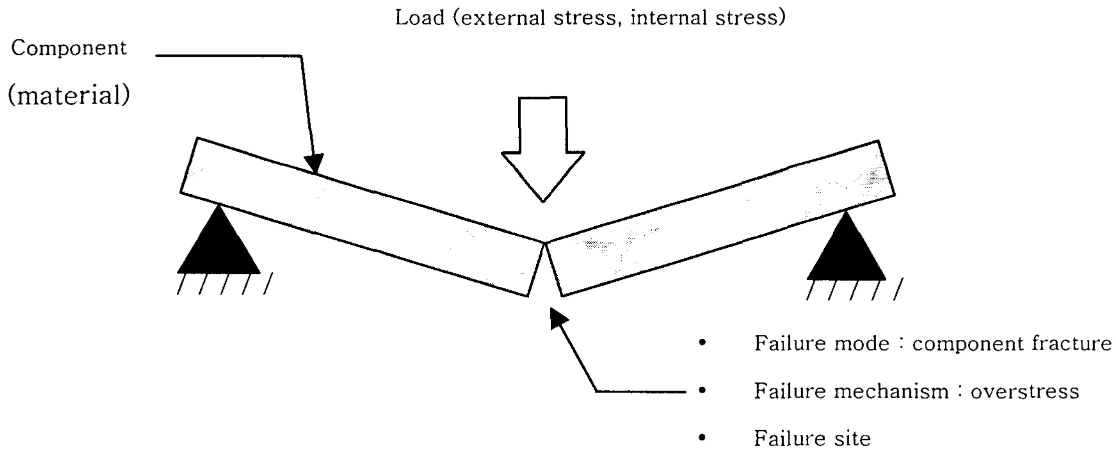


Figure 2. Failure Mechanics

What can prevent components from breaking? The correct action allows two options. One is to disperse the stresses over the whole component or to avoid them. The other is to exchange the materials for stronger ones, which can include coating and/or painting the materials to prevent them from being infiltrated by moisture or gases. Appropriate solutions mean altering the structure, dispersing the stresses, and/or replacing the materials.

Three major points define reliability: structure, load, and material. Structure can also be understood in terms of different stresses and materials. Changing structure for good reliability means an improved configuration of strong materials receiving rated stress, and/or dispersing stresses in order to avoid concentrated stress. Therefore, reliability is best conceived of as the relationship between stresses (loads) and materials (strengths). Therefore, two conclusions can be drawn about increasing reliability:

- Design and specification changes should be required before inspection because it is useless to meet unreliable or incomplete specifications, which should be revised for improved reliability. Especially, re-establishing specification for flaws in materials avoiding failure should be made. Thus, the technique for reliability pertains to design technology, not to manufacturing field as shown in Figure 3.
- Deciding how to increase reliability is another thing altogether from developing the performance of all products. Specialists of reliability can solve the reliability problems of rockets and vehicles as well as television sets because those products are respectively a certain configuration of available materials on earth under estimable environmental and operational stresses. Thus, the technique for fostering reliability growth is a common technology applicable to all manufactured products.

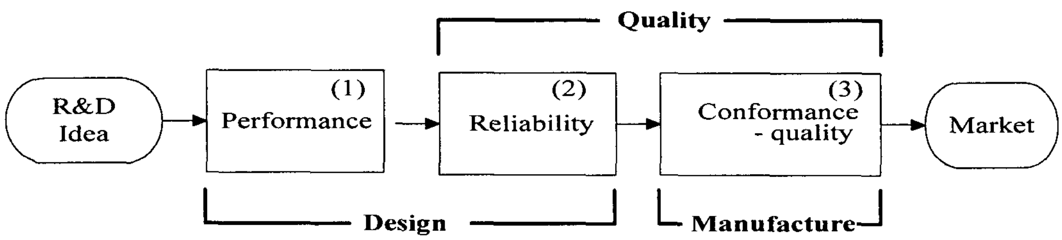


Figure 3. The concept of quality

Once the product has been designed for customer satisfaction and comparative advantages over competitors, operational stresses produced by the structure expressed with drawings and manufacturing specifications are conformed. Environmental stresses are rated and determined in accordance with the consumer's real situation. This means that both rating stresses and selecting materials for the product have been completed. The reliability of a product is already determined at its birth and thus is an intrinsic characteristic of the product.

2.3 The bathtub curve and hockey-stick line

In many reliability textbooks, the failure rate over the entire product life is explained by the bathtub curve. The bathtub curve depicts three regions: the decreasing rate of failure, the constant rate of failure (sometimes a slanted line, slightly increasing toward the righthand side), and the increasing rate of failure, as shown in Figure 4.

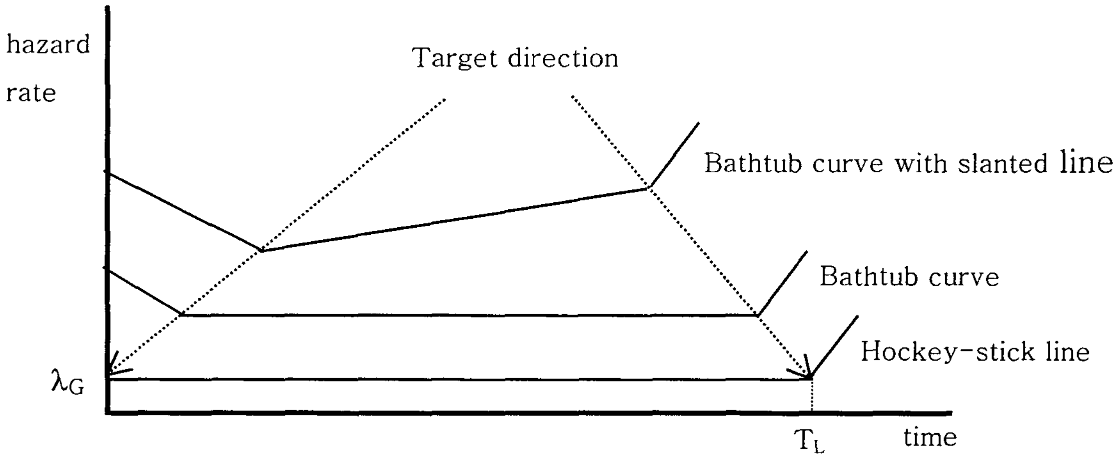


Figure 4. The bathtub curve and hockey-stick line

The decreasing region of the bathtub curve is called initial failure. Some products fail epidemically, after product release, due to unexpected environmental stresses, which are never anticipated in the design stage and/or, to which product designs are not in consideration of ample safety margin. Some fail due to big flaw in materials or major damage to the components during manufacturing, which is not screened out because of incomplete specification about flaw/damage and improper c-quality control system.

The constant region of the bathtub curve called random failure, presents a steady state of failure occurrence in which failures of the product occur rarely, but proportionally to time. This is a positive state as long as the failure rate is low and acceptable to customer.

What is random failure? It is unrealistic to assume the product will endure applied stress within the stated environmental and operational conditions established in the design stage. But there is always a very small chance that the product will receive an unpredicted crucial stress like lightning surge in television sets or pothole shock in vehicle. There is one limitation: the higher the stress, the less is its chance of receiving it. In trivial percentages, the materials in products of a good quality-controlled company might have flaws and be weakened during manufacture, which cannot be detected through inspection processes. There is another limitation: the greater the defect, the less is its chance of passing through manufacturing processes and being released into the market. These two limitations satisfy the premises of the Poisson process; we can apply the exponential distribution function, derived from the Poisson distribution function, to the constant region of the bathtub curve (random failure). The failure rate is constant to the unit of time until the product life limit and accumulated failure rates proportionally increase to the use time, within about 20 percent of cumulative failures as mentioned earlier.

Sometimes during use, the failure rate of a poor product has a propensity to increase toward the product life limit, demonstrating the wear out failure mechanism is operative during the working period. So this line in the bathtub curve is not parallel to the first; it is a little higher toward the righthand side. A good product shows no wear out failure and minimum random failure during its working period.

The rapid increasing region of the bathtub curve refers to wear out failure. As the working time of a good product approaches its life expectancy, the failure rate will increase significantly. After this point, wear out failure like fatigue or corrosion will occur. This turning point is the span of product life, or life expectancy, which is the starting time of wear out failure different from MTTF.

What shape of the failure rate curve is an appropriate business target? If the failure rate of a product goes along the bathtub curve, the product has no chance to succeed in the market. Big initial failures may damage the brand image from product launch. A high random failure rate, with or without slight wear out failures during the operating period, results in higher warranty expenses than experienced by a competitor who repairs products within the desirable life or warranty period. If a high failure rate and short product life are communicated among consumers, the market share of the product will shrink.

So we can extract a target for excellent products with respect to reliability:

- Reduce initial failure to zero, do not just minimize.
- Minimize random failures confirming that there exists only constant failure—without any kind of wear out failure during the working time.
- Lengthen the product life compared with that of competitors' products delaying the occurrence of wear out failure.

Eliminating the initial failure of new products means that the shape of the bathtub curve is changed, as shown in Figure 4, into a line, not a curve. We can call this the hockey-stick line due to its rather familiar shape. So, the failure rate of a bad product proceeds along the bathtub curve, while the failure rate of a good product follows the hockey-stick line.

2.4 Two meanings of reliability

Consider the hockey-stick line, as shown in Figure 5. Two important points in the x and y axes of hazard rate function, T_L and λ_G, precisely match the definition of reliability.

Reliability is defined *as the ability of an item to perform a required function under stated environmental and operational conditions for a specified period of time*. According to this definition, there are two unknown variables to be measured: ability and time. *A specified period* of time refers to product life (T_L). *Ability* means the level of performance that will be acceptable to the customer. This can be approximately calculated from the failure rate and the product life within about 20 percent of cumulative failures:

$$R(T_L) \cong 1 - \lambda_G \cdot T_L. \tag{2.1}$$

Therefore, in the hazard rate diagram, the term *ability* can be converted to changed measurement, the failure rate, λ_G.

The definition of reliability thus has two measurements, failure rate and product life, shown as the hockey-stick line.

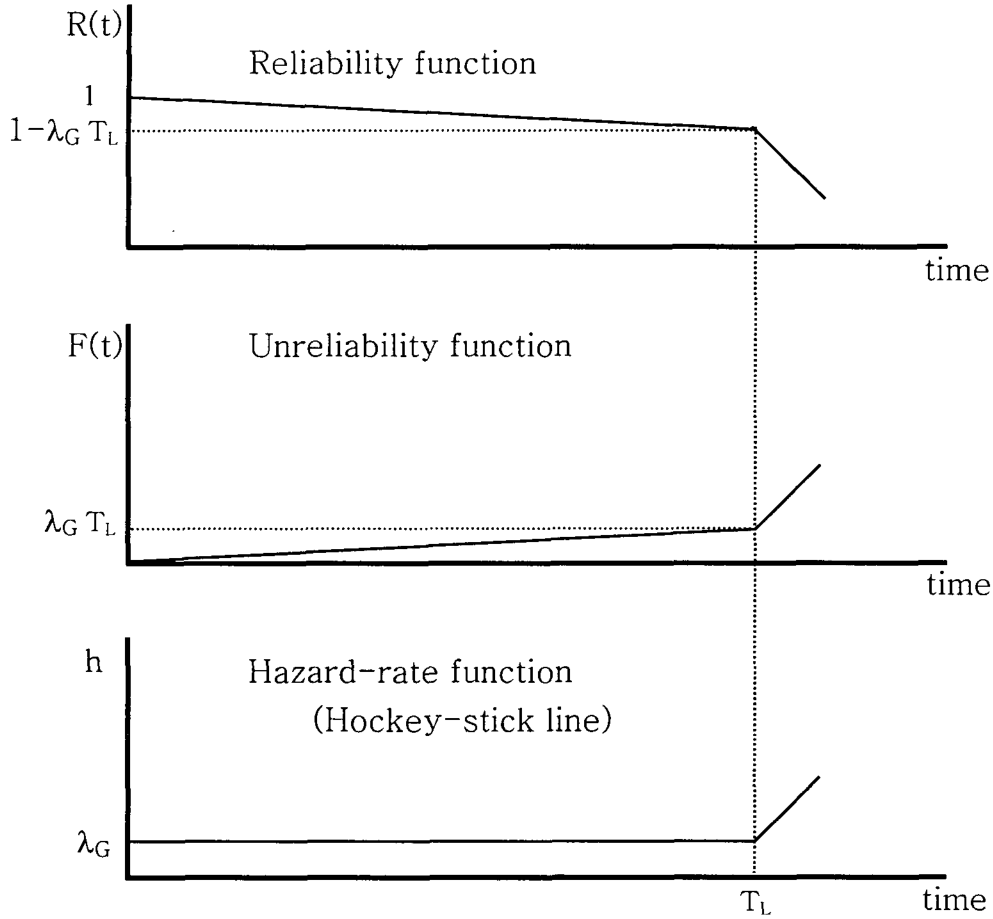


Figure 5. Two measurements in the hockey-stick line

Although good reliability produces both a lower failure rate and longer product life, some specialists regard reliability to be only the failure rate and use **durability** as the word regarding product life. Many technical articles use both the expressions reliability and durability. So there are two possible meanings of the terminology of reliability. (Afterwards rate-reliability refers to reliability regarding only failure rate and is abbreviated to r-reliability.)

The term *quality* is an ambiguous word encompassing c-quality and reliability. *Reliability* is also an ambiguous word comprising durability and r-reliability. The concept of quality includes reliability, and the concept of reliability includes durability. This produces a double ambiguity, and now we can arrange the concept of quality as shown in Figure 6. This double ambiguity distracts directors and managers from pursuing the correct way to improve c-quality and reliability.

Meaning of Quality	Quality		
		Reliability	
	Quality (c-quality)	Durability	Reliability (r-reliability)
Concept	Conformance to Specifications	Product Life	Failure Rate
Recommended Units	Percent ppm	Year Hour	Percent / Year Percent / Hour
Probability density function	Normal Distribution Function	Lognormal Distribution Function	Exponential Distribution Function
Activities	Inspection, Screening	Design Change or Completion of Specification	

Figure 6. The double ambiguity of quality

Why are durability and r-reliability so important? Manufacturers of durable products will encounter catastrophe if their products have high failure rates and/or short life expectancies and if some failures lead to consumer's risk. Therefore, the suitability of products for a success without disaster should be carefully estimated, taking into consideration the critical influences on user and product that failures would bring forth in the future.

Recently, Dow Corning met disaster paying 3.2 billion dollars to consumers in 1998. It's a reliability problem. The breast augmentation should not fail until the consumer reaches her eighties, even if she bought and received the implant in her twenties. This implies that the durability of silicon-gel implants should be over sixty years. If there are epidemic failures within acceptable product life to consumers, the product release should not be permitted because such failures would diminish product life as much and damage corporate revenue.

And then, how low a failure rate should they have, in order to be successful as a long-run product? What considerations should be given to pricing a brand new product to account for failures? The number of annual failure cases by each failure mechanism might be calculated as its annual failure rate (f_i) multiplied by annual sales quantities (Q). Annual reimbursements will then be the summation of the above number of failure cases multiplied by the average service expense and payback of each failure mechanism (E_i). So, if it is warranted for sixty years product life (L), total reimbursements or warranty cost (Wc) would be extended to sixty times annual reimbursements. Therefore, annual profit (Pa) should cover the expenses of the total reimbursements over the product life:

$$Wc = \sum_i f_i \times Q \times E_i \times L, \qquad (2.2)$$

$$Pa >> Wc.$$

If core parts should be replaced, as a dominant failure, without charge, the annual failure rate must be very low. If a service trip fee can be costed for a simple problem like a parametric shift, the annual failure rate could be a little higher.

The executives handling new product development should predict durability and r-reliability and calculate warranty cost in advance of the product's release into market.

2.5 How to improve reliability

In advance of the prediction of reliability, it is necessary to identify the form of failure rate over entire product life and improve reliability, similarly or just fit to hockey-stick line. What steps should be taken in this direction?

First, the product and/or components should be tested over time, under more severe environmental and operational conditions than the projected customer use. Short-period testing can mainly identify initial failure modes, while long-period testing can reveal failure modes occurring in working time and adjacent product life. Testing over time can identify the failure mode of the weakest site in the product and provide an analysis of dominant failure mechanism. The product designer should take appropriate measures to eliminate that failure.

Secondly, reliability improvement should focus on the next weakest site. The designer must change the product drawings and specifications, dispersing stress over better material, avoiding the failure mechanism. In consequence, the failure rate of the product will drop and product life will increase.

The analysis of overstress failure mechanism and flaw-induced failure mechanism can contribute to eliminating initial failures and reducing random failures. It can avoid such failures widening safety margin to the rated stress and reducing defects/flaws in material. Especially, according to the analysis of flaw-induced failures it is essential to establish the specifications of material flaws including its size, location, shape etc, in order to eradicate initial failures. And the analysis of wear out failure mechanism determining product life can give right direction to lengthening product life.

At this point, add that failure analysis technology can not only reduce the failure rate, but also extend product life. Both meanings of reliability—durability and r-reliability—can be addressed through one kind of technology. Because product life can be lengthened through failure analysis technology, some specialists call it reliability growth, not quality improvement.

Again in short, the steps for reliability growth are as follows: (1) Identify the failure modes through testing over time. (2) Analyze failures and determine the failure mechanism. (3) Change structures and/or re-establish specifications according to the results, and confirm the validity and the side effects of design change.

As a first step, finding failure modes is requisite. But it is not easy to identify, now and here, all the failure modes occurring over entire product life. And it becomes harder as the reliability of a product has been improving in the current competitive market. It might be necessary to extend testing time and increase the number of test samples, and test conditions might need to be far more severe than actual operating conditions. Note that the failure mechanism should not be changed due to accelerated test conditions.

In order to properly test the product or components for failure finding, studies are needed in three areas:

- The product itself—that is, many different assembled components constituted of various materials and fabricated by various connection technologies (soldering, calking, etc). The materials inside the product must be analyzed in detail.
- The environmental and operational conditions that the product or component must endure during its lifetime. This means examining the stresses produced by various environmental and operational conditions.
  These two studies of operating stresses and the materials inside the product, corresponding to the two possible reasons for failure can point up potential failure mechanisms. These studies respond to the inputs of IEEE Std 1413-1998(IEEE Reliability Society (1998)).
- The appropriate test method. This involves selecting and building up the test system with appropriate test conditions and procedures responding to the possible failure mechanisms(Evans and Evans(2001)). The most important issue in the test method configuration is how early the potential failure mode can be found with how small quantities of sample.

General test methods can never find all the failure modes, and sometimes cannot even find the dominant one. Different failure mechanisms require different test methods. Therefore, test methods should be reviewed based on the analysis of failure. Over fifty failure mechanisms have been identified so far (Evans and Evans(2001), Ryu(1999)).

Finally, after testing the product and analyzing failures, the failure rate and product life should be estimated. If the estimates meet the reliability targets, a reliable product will result.

2.6 Target settings of reliability and c-quality

Appropriate target settings of reliability and c-quality are very important for good quality, but frequently mishandled by directors in business and industry.

Customers regard the product not to be a technological complex but a convenience—good performance, ease of use, no-trouble. Therefore, the quality of products should be acceptable as a whole, regardless of the type of products such as home appliances, motors, and aircrafts, or the quantities of components incorporated into products.

First, how low should be the r-reliability of components incorporated into a successful product? The failure rate of the product is the sum of the failure rates of all components and connections. And assume that the annual failure rate of products such as televisions, motors, and airplanes would be sufficient if it neared 1 percent/year (except for crucial accidents like fire in the television, a sudden rush of the motor, or a nose-diving crash of the airplane). Let's assume that the number of components is about one thousand in the television, ten thousand in the motor, and a hundred thousand in the airplane and that the annual operating hours of three products are close. Finally, let's assume that a small electronic component is commonly incorporated into all three products.

The component must be reliable, so the targets of the annual failure rate of that part should be below 10-ppm/year in the television, 1-ppm/year in the motor, and 0.1-ppm/year in the plane respectively even though its life may satisfy the durability target of each product.

Clearly, reliability is much more difficult to achieve in a sophisticated product than in a simple product with fewer components. The Boeing 777 has 700,000 numbered parts. To maximize durability and r-reliability, the 777 program utilized only field-proven technologies, backed by extensive testing. Physical prototypes were laboratory-tested— under severe environmental conditions before any parts or systems were incorporated into the first aircraft— executing performance and stress analysis through the three-dimensional design system(Swink(1996)). Therefore, it is important to review, with predetermined target, the reliability of components and sub-systems of sophisticated product in early design stage in order to reduce failure cost.

Secondly, how low should be the defect ratio of c-quality? In Korea, many companies are struggling to improve quality through single-ppm movements, which means that every product has a c-quality defect level of a single-ppm. In America, manufacturers such as Motorola and GE boost six-sigma movements—that is, related components have basically c-quality defects within 3.4-ppm under the assumption of 1.5-sigma deviation of the average of collected data from the center of specifications.

Is it possible to achieve desirable c-quality if all components meet that specified ratio; around 10-ppm? Is this an appropriate target of c-quality management?

It is, under two conditions:

- The product has already met reliability targets, with low annual failure rates and long life expectancy.
- The number of the components in the product does not exceed a few thousand.

In terms of reliability, the first condition might be easily understood. When reliability problems occur at a slightly higher rate, which means specification changes are necessary, the activities of conformance to the current specifications would be worthless.

Now, let's consider the second condition. Assume that, if the product has a thousand components, there would be a thousand fabricating processes like soldering, bolting, and fastening. Assume that the average c-quality defect ratio of every process is 10-ppm, including operator mistakes, equipment malfunction, and components out of specification. The c-quality defect ratio of the product (q_s) would be approximated by the following equation, on condition that the product of the average defect ratio (q_i) and number (n) of processes is sufficiently small(Ryu(1999)):

$$q_s \cong n \cdot q_i. \tag{2.3}$$

As there are a thousand processes with a 10-ppm average c-quality defect, the total c-quality defect ratio of the product is calculated as 1 percent. One percent c-quality defects might be affordable in the business. However, if a product with components of 10-ppm defects is sophisticated, the defect percentage of the product would be ten times greater in a motor with ten thousand components and sixty three times greater, not a hundred times because of over approximation condition, in an airplane with a hundred thousand components than in a television with a thousand components.

So the target of c-quality defect ratio should be below 1-ppm in the motors and below 0.1-ppm in the airplanes. The limit for the number of c-quality defects should be decreased proportionally to the inverse of the number of the processes and/or components in the product.

Note the following conclusions:

1. Durability targets should be fixed equally to all constituents corresponding market situation and r-reliability targets should be determined according to the number of product components. And add that the durability should be estimated not to be MTTF as mentioned earlier, but to be, for example, B_{10} life—the time of 10 percent cumulative failures of product.
2. C-quality defect targets should be determined according to the number of product components.

To achieve quality improvement, quality control systems in manufacturing should follow these three steps:

1. Product drawings and manufacturing specifications should be reviewed to achieve reliability growth.
2. Analyze manufacturing processes; make procedural changes; newly install inspections to reduce c-quality defects.
3. Review the total quality system and reorganize reliability-quality control systems as needed to achieve effective and rapid corrections, so that the quality system does not allow deficient components to enter the factory or deficient products to leave.

The first two steps cannot be performed in reverse. Figure 7 shows the activities related to c-quality defects and reliability failures.

Category	**Reliability failure**	**Conformance-quality defect**
Approach	Vertical Identifying root cause	Horizontal Inspection and screening
People	Team members Developer and failure analyzer	All members All manufacturing employees
Who's in charge	R&D part chief (R&D manager)	Factory director (Q.A. manager)

Procedure	Find failure mode and site Analyze failure Determine failure mechanism Assess failure rate and product life Propose alternatives	Enumerate quality characteristics Confirm process capability Decide the kind of inspection— sampling, all or double Determine inspection position
Results	Alter design and manufacturing specifications	Rearrange quality inspection system Train inspector

Figure 7. Reliability failure and conformance-quality defect

3. THE CONCEPT OF PRODUCT QUALITY

3.1 Five factors of product quality

Product quality has emerged as one of the most important concepts in business and industry, because improving product quality leads to increased market share and high return on investment(Schnaars(1991)).

Product quality is different from the quality of a product. A product without reliability failures and c-quality defects is desirable, but may not prevail in the market. Customers select a product based on comparative advantages when they want to buy it, and they should feel satisfied using that product. A failure- and defect-free product is not sufficient in the customer's mind.

As mentioned in the introduction, professor Garvin, in a Harvard Business Review article, lists eight dimensions of product quality, as shown in the left half of Figure 8, which is very valuable classification to grasp the meaning of quality. But it would be difficult for managers in business and industry to improve each dimension of the product quality according to his classification because there is no implications of how-to-approach. Concern should be focused on methodologies that enable them to improve each dimension of the product quality to achieve higher market share—that is, those technologies that can make the product quality more attractive to the customer.

Performance (dimension #1) is the basic concept behind the product. To design for performance, every product has its own field of technology. In the case of television, for example, transmitting and reproducing of picture and sound can be obtained by electronic engineering. So performance can be considered an independent one.

Reliability (dimension #2: r-reliability) and durability (#3) can be fully improved through failure analysis technology as mentioned earlier. As integrated into one, the two dimensions are better understood, *reliability*. Serviceability (dimension #4) is an annexed dimension of reliability; upgraded reliability minimizes service activity, which is profitable.

Conformance to specifications (dimension #5) means c-quality based on statistics and manufacturing technology.

It is inadequate to divide quality, broadly speaking, into four dimensions: reliability, durability, conformance to specifications, and serviceability. Separating quality into two is enough: reliability and c-quality; alteration of specifications for reliability growth, and inspection for zero defect of c-quality.

The remaining three dimensions—product features (dimension #6), aesthetics (#7), and perceived quality (#8) also need to be well arranged. These three dimensions can be initiated and surveyed through market research—identification of the basis for customer satisfaction.

The preferable configuration of product features can be determined through customer research, which can reveal the product features that seem fresh and attractive to the customer. In terms of industrial design or aesthetics, market research can locate the right position of the product in an image map, such as using multiple correspondence analysis between images and brands. Market research methods, searching relationships between images and aesthetic elements, can identify the right direction to consider in improving product aesthetics(Shin, Park et al.(2001)). It can also explain the elements of perceived quality. For example, the customer can be surveyed through questionnaires about the attributes of the product and services, which are important but unsatisfactory, and about factors that influence purchase behavior in order to clarify perceived quality. Thus, the three dimensions of product features, aesthetics, and perceived quality can better be integrated into one-*customer perception*, because these three dimensions are based on customer's cognition.

Of course, developing one special product feature discerned to be desirable through customer research could be attained by electronic or other engineering. Unsatisfied strategic attributes, identified by survey, may be failures that can be solved by reliability technology, but such activity follows after the analysis of customer perception through market research.

Eight Dimensions by Garvin(Garvin(1987))	**Five Factors by related field**
1. Performance	1. Performance
2. Reliability 3. Durability 4. Serviceability	2. Reliability
5. Conformance to Specification	3. Conformance to Specification
6. Product Features 7. Aesthetics 8. Perceived Quality	4. Customer Perception
	5. Fundamentals Advantage

Figure 8. Eight dimensions by Garvin and Five factors by related field

Now, Garvin's eight dimensions are reduced to four as shown in the right side of Figure 8: performance, reliability, conformance to specifications and customer perception.

However, another dimension of product quality cannot be solved with these technologies and methods—performance advantage sensed by consumers. Brand differences in product performances will be detected after extended use by consumers. Yet surveying performances through customer research represents the outcome of relative and indirect assessment. Then, which fundamentals of performance make that brand feel good? It is important to know why and how much fundamentals characterize product performance for excellence. These characteristics of fundamentals should be scrutinized and clarified.

Most specialists accept that the picture quality of a television consists of fundamentals such as gray scale, white balance, sharpness, and so on. For example, in order to achieve optimum gray scaling for good picture quality, the principle of intensity should be applied to the adjustment logic of brightness as the characteristic. The German scientist E. H. Weber reported in 1846 that the intensity of luminance should increase exponentially to give the next unit of light apprehension (Weber fraction). Controllable instruments producing various gray scale should be developed, and with them optimum scaling should be selected according to its characteristic and validated by the focus group of customer(Ryu and Choi(1999)). This can be obtained not by simple performance design technique utilizing electronic engineering but by physics research with precise scientific measurements.

Fundamentals advantage is last one for excellent performance. Improving fundamentals advantage consists of four steps: (1) Extract the fundamentals of performance of the product. (2) Scrutinize and analyze the characteristics of the fundamentals. (3) Develop more accurate ways to measure these characteristics. (4) Measure, evaluate, and take action.

Customer perception about performances describes product quality from the customer's viewpoint; fundamentals advantage is product quality from the physicist's.

Fundamentals advantages in performance usually allow sales personnel to easily recommend the product to customers. If a product has absolute fundamental advantages, differentiated securely by registration as intellectual property, and if a good image is given to the customer, it is highly beneficial to sales. Of course, it is best to report on absolute advantages in related symposia and to acquire credibility from specialists. But if customers are satisfied with the fundamentals and confirm it directly, the product will become a best seller.

Currently, the classification of product quality is divided by the technology and methodology needed to properly improve product quality. It would be better to call these factors, not dimensions because each factors has its own related technology influencing product quality. Product quality thus has five factors as detailed in Figure 9.

The first three factors are necessary conditions for a product to be born as shown earlier in Figure 3. The last two are conditions required to enlarge market share. Successfully fulfilling the necessary factors for product quality does not mean that customers will appreciate the resulting product. In addition, the required factors for product quality will make the product preferable to customers.

Finally, whether or not the product will survive in the future would be unpredictable without both data gathered from the customer (factor #4) and an advanced technological edge for competitive advantage (#5). The combination of current market information and advanced technology enables a company to develop advanced products and flourish in the market.

	Factors	Objective (example: TV)	Related Field
Necessary factors as a product	1. Performance	Principle of reproducing picture and sound Theory of transmission	Electronic engineering Transmission engineering
	2. Reliability	Analysis and elimination: · fracture of cabinet · solder joint fatigue of PCB · degradation of picture tube	Fracture engineering Mechanics of materials Chemistry Statistics (exponential, lognormal, weibull function)
	3. Conformance to Specifications (c-quality)	Quality inspection system Building the manufacturing process	Statistics (normal distribution) Manufacturing engineering
Required factors preferable to customers	4. Customer Perception	Attributes of product performance and marketing activity	Research in marketing Marketing Aesthetics
	5. Fundamentals advantage	Superiority of picture and sound	Physics Basic science

Figure 9. Five factors of product quality (TV product)

3.2 Creating the first-class product

So far, the five factors of product quality have been explained for directors and managers for easy follow up. Here, let's think about the relationships among factors.

Conformance to specifications is not related to determining specifications, though the other four factors are; so *conformance to specifications* is addressed last. The activity of *reliability* is altering specifications without changing product performance. The activity of *fundamentals advantage* is measured and improved after development of a new model based on *customer perception* data. These relationships imply the procedure for creating a first-class product, as seen in Figure 10.

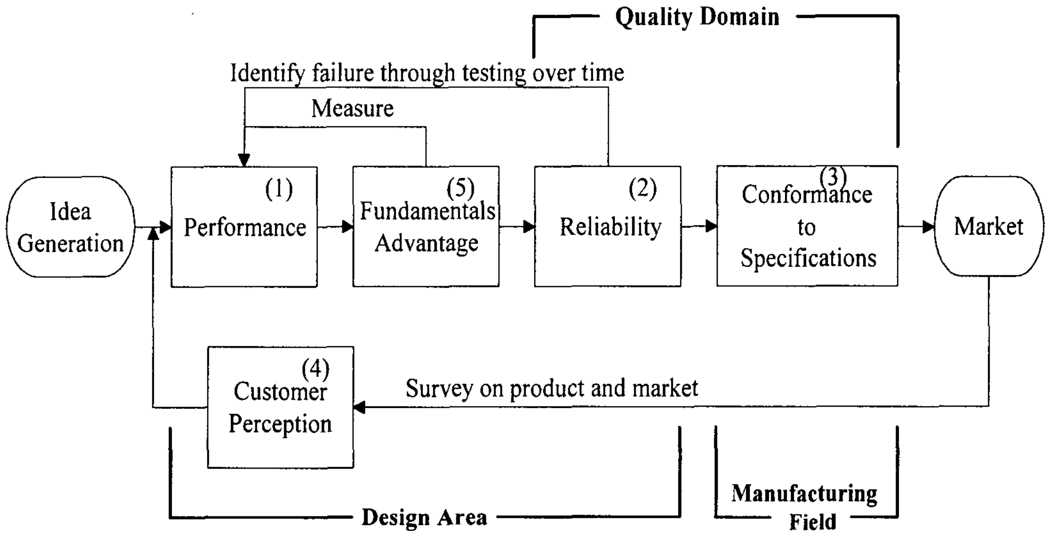


Figure 10. Relationships of product quality factors

Now we can briefly discuss how to incorporate the five factors of product quality into a product. Product developers design, basic performance and additional features (1) with their ideas, based on *customer perception* data (4), then adjust and revise performance according to evaluated details of *fundamentals advantage* (5). Drawings and specifications are reviewed by failure analysis engineers for reliability growth (2) and then confirmed if durability and r-reliability meet targets. People in the manufacturing process make the product *conform to the specifications* (3) with various manufacturing technique including statistical tools.

This well organized co-work enables a company to position its product in the top class. Only when the five factors of product quality are integrated into the product as a whole, can a first-class product emerge.

In addition, product technology can be divided into design and manufacturing technology. Design technology comprises four factors except *conformance to specifications* and *conformance to specifications* pertaining to quality responds to manufacturing technology. Note that *reliability* pertaining also to quality responds to design technology.

4. FROM INCREASED PRODUCT QUALITY TO BUSINESS PROFIT

If the product quality in a company could be improved somewhat, the company might gain greater profit—that is, improved product quality and/or decreased price pushes product value higher(Gale(1994)); value contributes to market share increase; and market share increase enlarges profit. Here, we derive mathematical equation between product value and market share, which is **new** and **simple to apply**—a **missing link** in business management, by which we can connect product quality to corporate profit.

We propose to rearrange the profit equation, especially for durables, because reliability has a direct influence on business profit.

With these two equations, CEOs and managers can estimate the profit of the new product after mockup modeling and before mass manufacturing.

4.1 Market share increase

Market demand is determined by product value and the disposable income of the customer, which is an economic consideration influenced by factors from different fields. Company total demand is the result of market demand multiplied by market share. Market share is the aggregate of customers' selection in consideration of product value calculated mentally from product quality and price. The product value projected to a customer is an expression of market share, a unit of simple percentage.

The major issue is how much a new product can gain in market share, **breaking the current equilibrium among competitors**. If a company is now selling a product and finishes developing a new competitive product as a substitute for it, what will be the estimated increase in its market share?

A well-tested hypothesis that higher value earns higher market share holds that the market share of each company is proportional to a certain power of the product value that the company delivers into the market(Gale(1994)). Market share is defined as

$$S \equiv \frac{V^{\alpha}}{V^{\alpha} + \sum_{i=1}^{n-1} V_i^{\alpha}}, \qquad (4.1)$$

where S = market share of company A,

V = product value of company A,

V_i = product value of the i-th competitor,

α = market orientation index of product value : value multiplier to the market .

Here, product value can be defined as the linear combination of both product quality attributes and price attributes, which are discussed in detail by Bradley T. Gale in the name of customer value(Gale(1994)):

$$V = \sum a_i q_i + \sum b_i (1/p)_i, \qquad (4.2)$$

where q_i = product quality attributes,

$(1/p)_i$ = price attributes,

a_i, b_i = attribute coefficient.

The attributes and their weight of the product quality and price can be surveyed and determined through market research. These might be varied according to the type of product and its market. Note that a number of product quality attributes can be extracted through focus group interview and classified according to the factors of product quality to improve product quality.

Now, the oriented relative value increment of new product, R, to the current product is defined as

$$R \equiv \frac{V_N^{\alpha}}{V^{\alpha}} - 1, \tag{4.3}$$

where V = product value of current product of company A,

V_N = product value of new product of company A.

From the definition of both market share and of the oriented relative value increment, the market share increase, ΔS, and the market share of new product of company A, S_N, is mathematically derived as follows (see appendix):

$$\Delta S = S(1 - S)R/(1 + SR), \tag{4.4}$$

$$S_N = S(1 + R)/(1 + SR). \tag{4.5}$$

The market share increase can be calculated with only two parameters—the market share of the current product, S, and the oriented relative value increment, R.

The fraction term, $1/(1+S\cdot R)$, becomes a reduction factor that explains the competition situation of the company A in the market.

The market share increase, ΔS, would be the maximum share because of the assumption that the new product value would be well recognized by the customer and that other competitors' product values remain unchanged. And add that the form of this equation remains invariant regardless of the definition of product value; this allows each company to develop the practical definition of product value, which is suitable for its product and market situation; Thus, CEOs and managers can estimate market share increase before a new product release into the market.

In addition, when the relative value increment, ΔV/V, is sufficiently small, the equation of market share increase is changed to a linear relationship as followings (see equation A.12 in appendix):

$$\Delta S_A \cong S\cdot(1 - S)\cdot\alpha\cdot\Delta V/V, \tag{4.6}$$

where $\Delta V \equiv V_N - V$.

This equation indicates that the market share increase is proportional to the relative value increment, ΔV/V, and market orientation index, α—value multiplier to the market, which might be characteristic constant determined from the definition of product value and the type of product in the market.

Finally, let us consider the situation that competitors have also increased their product value. Then the market share of company A is changed to the following equation

$$S_N = S(1 + R)/(1 + SR + \sum_{i=1}^{n-1} S_i R_i), \tag{4.7}$$

where S_i = present market share of the i-th competitor,

R_i = the oriented relative value increment of new product of the i-th competitor's.

Here, as an application, this equation also clarifies the reason why a company neglecting development of new products might easily fade out when many competitors incessantly renovate their products. Assume that several companies have equal product value and market share, and that all but one would strive to improve product value similarly with one another. The result is that the sum of market share increase of the improving companies exceeds the market share of the one company neglecting new product development, as in the following equation:

$$\sum_{i}^{n-1} \Delta S_i \geq S_n, \tag{4.8}$$

where ΔS_i = market share increase of the i-th company improving product value,

S_n = market share of a company not improving product value.

Where $\Delta S_i = \Delta S$,

then,

$$(n-1)\Delta S \geq S_n. \tag{4.9}$$

Now substituting Equation (4.4) for market share increase, ΔS:

$$(n-1)(S)(1-S)\cdot\frac{R}{1+S\cdot R} \geq S_n. \tag{4.10}$$

Where $S = S_n = \frac{1}{n}$,

then,

$$R \geq \frac{1}{n-2}. \tag{4.11}$$

This result is plotted in Figure 11. When five out of six companies endeavor to increase product value, the oriented relative value increment, 25 percent, would be sufficient to push the other company out. Therefore, when a leading company releases a new good product and competitors speedily follow the leader's model, if one company cannot catch up, it is likely it will disappear from the market.

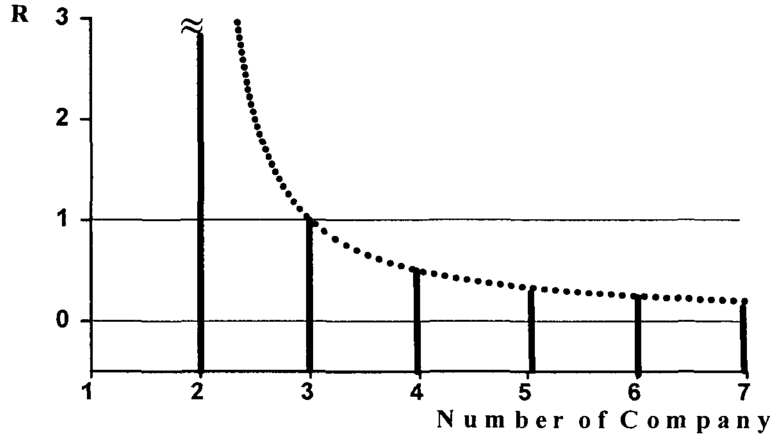


Figure 11. Oriented relative value increment for fading out one company

And add that 25 percent of the oriented relative value increment, R, would approximate to 2.5 percent of the relative value increment, $\Delta V/V$, when value multiplier, α, reaches to 10, which means that tiny value increment would result in great effect as following (see equation A.5 in appendix):

$$R \cong \alpha \cdot \Delta V/V. \tag{4.12}$$

But when three companies are competing, two need to increase their oriented relative value increment by 100 percent to make one slow-moving company fade from the market. This might not happen often because it requires a quantum leap in product value, but it can and does occur.

4.2 Profit equation for durables

Usually, the annual profit (Pa) can be expressed as

$$Pa = P \times Q - C, \tag{4.13}$$

where P = price,

Q = annual sales quantity,

C = cost.

With this equation, managers can empirically estimate profit in the planning stage. However, they cannot clearly analyze the estimated results, because cost includes warranty costs mixed with materials and manufacturing costs. For durables, warranty cost, which is related to reliability in product quality, is particularly critical in business, as explained previously; it should be calculated from the annual failure rate and product life, which are estimated from test results before product release. So it is beneficial for a product planner to separate warranty cost. Actually, since warranty cost will be confirmed from market service data after product sales, it is adequate to separate warranty cost (Wc) time-dependently and set its target in advance of product release.

Then, the profit equation changes:

$$Pa = (P \times Q - Cm) - Wc, \tag{4.14}$$

where Cm = material, manufacturing and development cost,

$$Wc = \sum_i f_i \times Q \times E_i \times L.$$

As explained earlier, after-sales service problems are closely related to reliability. If managers understand the intrinsic character of reliability through failure analysis technology, they can list failure mechanisms in the product and assess durability and r-reliability before product release. They can thus calculate warranty cost as the minus term of profit.

Low cost implies that the maker can develop, design, and manufacture products with managerial and technological competitiveness based on employee's ideas. It represents the integrated result of the innovative activity of company employees.

Pricing is a strategy. There are two kinds of pricing: skimming strategy and penetration strategy. If you develop an excellent product without any competitors, you might follow the skimming strategy. If there would be many competitors, penetration pricing would vary according to the business situation. Higher pricing lowers product value and sales quantity. The opposite is true of lower pricing.

Sales quantity increases due to the product value increment—improved product quality and/or decreased price, which is made possible through lowering cost.

Now we can briefly discuss how to estimate profit according to new product. Before product launch, managers can calculate market share increase due to improved product value. With a firm price and increased market share, total revenue can be estimated. Gross profit can be calculated by subtracting costs gathered from internal data. Then genuine profit can be estimated by subtracting warranty cost, according to estimated calculation data from reliability test results.

Business success of a new product would be precisely anticipated in planning stage.

5. CONCLUSIONS

To clearly grasp the concept of quality, the double ambiguity about quality should be understood.

The broad concept of quality includes reliability—that is, it encompasses both reliability and c-quality. C-quality means conformance to specifications. This is the first ambiguity.

Reliability means no failure inside product till product life limit. Determining the reason why failure occurs leads to alterations in specifications toward reliability growth. Therefore, activity to improve quality should be pursued in two directions characterized by different dimensions, units, and probability functions: validation of the specifications for reliability growth and conformance to the specifications for c-quality improvement.

Meanwhile, the commonly used bathtub curve may not be the best to apply to creating a preferable product for the customer; a better curve to describe the failure rate of a successful product in the market is shaped like, and can be called, a *hockey-stick line*.

From the definition of reliability and the hockey-stick line, two measurements can be extracted—product life—durability and failure rate—reliability. Reliability consists of durability and r-reliability. R-reliability refers to reliability regarding only failure rate. This is the second ambiguity.

In order to improve the reliability of a product, three studies are needed. Studies on both the stresses induced by environmental and operational conditions and on the materials inside the product—two key elements of failure—allow anticipating possible failure modes and failure mechanisms. Study of test methods will help find effectively failure modes same as field phenomena. Thereafter test results will identify failure modes, and failure analysis outcomes will point toward possible solutions for reliability growth.

And add that the target settings of r-reliability and c-quality should be determined in consideration of product complexity, while that of durability should be fixed equally to all constituents.

The concept of *product quality*, which might increase customer preference, is quite different from that of the quality of a product.

Five factors of product quality are pertinent. The eight dimensions described by D. Garvin can be reduced to four factors of product quality; the fifth factor is product excellence. These five factors can be classified according to their relevant fields of technology and methodology: (1) performance, (2) reliability, (3) conformance to specifications, (4) customer perception, and (5) fundamentals advantage.

Finally, improved product quality can contribute to a market share increase on condition that product quality and product price push product value higher. The product value increment represents a market share increase, when market share is regarded as the result of competition of product value in the market. The market share increase, ΔS, is given in the following equation:

$$\Delta S = S(1 - S)R/(1 + SR),$$

where $R \equiv (V_N / V)^{\alpha} - 1$.

This equation yields the maximum market share increase for release of a new product.

Given the importance of reliability, the profit equation for durables can be rearranged as follows:

$$Pa = (P \times Q - Cm) - Wc,$$

where $Wc = \sum_i f_i \times Q \times E_i \times L$.

With these two equations, CEOs and directors can determine the best business situation in advance of new product launch and estimate the success of the product.

ACKNOWLEDGEMENT

The author wishes to express special thanks to Dir. Michael Pecht of CALCE Electronics Products and Systems Consortium in the University of Maryland for reviewing in depth. The author would like to express his appreciation to Dr. John W. Evans of Seoul National University for helpful discussion, Dr. Seongyong Park of Hallym University for his assistance on market dynamics, and Dr. Nagyoung Chang of Hanbit Technology Development Service, Inc. for reviewing mathematics. The author is also indebted to Mr. Timothy Schmidt of Holographic Inc. for advice and to specialists in Quality and Reliability Lab. of Daewoo Electronics Co., Ltd.

APPENDIX

Derivation of the equation for the market share increase, ΔS

Let us assume that a total number of n companies, including company A, are competing in a market, each trying to increase its market share of a certain product.

A well-tested hypothesis that higher value earns higher share holds that the market share of each company is proportional to a certain power of the product value that each company delivers into the market.

The market share of company A is defined as

$$S_A \equiv \frac{V_A^{\alpha}}{V_A^{\alpha} + \sum_{i=1}^{n-1} V_i^{\alpha}}, \tag{A.1}$$

where S_A = market share of company A,
V_i = product value of the i-th company in the market, i=1,2, ····· ,n−1,
V_A = product value of company A,
α = market orientation index of product value, $\alpha>0$.

Let us consider a situation in which company A, applies a technology development process to its product, thereby increasing the product value from $V_A=V_{AP}$ to $V_A=V_{AN}$, while the product values of the other competing companies remain the same.

Let us denote the value increment of the product of company A as ΔV_A,

$$\Delta V_A \equiv V_{AN} - V_{AP}. \qquad \text{(A.2)}$$

We can justifiably expect that the market share of company A will increase accordingly, from $S_A=S_{AP}$ to $S_A=S_{AN}$. This can be represented by the following expressions:

$$\begin{aligned} S_{AP} &= [S_A]_{V_A=V_{AP}}, \\ S_{AN} &= [S_A]_{V_A=V_{AN}}. \end{aligned} \qquad \text{(A.3)}$$

Let us denote the resulting market share increase of company A as ΔS_A,

$$\Delta S_A = S_{AN} - S_{AP}. \qquad \text{(A.4)}$$

Now, let us introduce an index, R_A, defined by the following equation:

$$\begin{aligned} R_A &\equiv \frac{V_{AN}{}^{\alpha}}{V_{AP}{}^{\alpha}} - 1 \\ &= \left(1+\frac{\Delta V_A}{V_{AP}}\right)^{\alpha} - 1 = \alpha \cdot \frac{\Delta V_A}{V_{AP}} + \frac{\alpha\cdot(\alpha-1)}{2}\cdot\left(\frac{\Delta V_A}{V_{AP}}\right)^2 + \cdots\cdot. \end{aligned} \qquad \text{(A.5)}$$

Here, R_A can be viewed as the oriented relative value increment of new product to the current product in company A.

We now inquire about the relationship between the market share increase, ΔS_A, and the oriented relative value increment, R_A.

The relationship can be derived as follows:

$$\begin{aligned} \Delta S_A &= S_{AN}\cdot S_{AP}\cdot\left(\frac{1}{S_{AP}} - \frac{1}{S_{AN}}\right) \\ &= \frac{S_{AN}}{V_{AN}{}^{\alpha}}\cdot S_{AP}\cdot R_A \cdot \sum_{i=1}^{n-1} V_i{}^{\alpha} = \frac{1}{V_{AN}{}^{\alpha} + \sum_{i=1}^{n-1} V_i{}^{\alpha}} \cdot \sum_{i=1}^{n-1} V_i{}^{\alpha}\cdot R_A \cdot S_{AP}. \end{aligned} \qquad \text{(A.6)}$$

Solving the definition of S_{AP} for the summation term yields

$$\sum_{i=1}^{n-1} V_i{}^{\alpha} = V_{AP}{}^{\alpha}\cdot\left(\frac{1}{S_{AP}} - 1\right). \qquad \text{(A.7)}$$

Solving the definition of R_A for $V_{AN}{}^{\alpha}$, we obtain

$$V_{AN}{}^{\alpha} = V_{AP}{}^{\alpha}\cdot(1+R_A). \qquad \text{(A.8)}$$

Now, substituting these two equations into Equation (A.6), we arrive at the following relationship:

$$\Delta S_A = S_{AP} \cdot (1 - S_{AP}) \cdot R_A / (1 + S_{AP} \cdot R_A), \tag{A.9}$$

$$S_{AN} = S_{AP} + \Delta S_A = S_{AP} \cdot (1 + R_A) / (1 + S_{AP} \cdot R_A). \tag{A.10}$$

The market share increase, ΔS_A, is predicted from only two parameters in Equation (A.9)— the current market share, S_{AP}, and the oriented relative value increment, R_A.

In addition, if $|R_A| << 1$, then Equation (A.9) may be reduced to the following approximate equation:

$$\begin{aligned} \Delta S_A &\cong S_{Ap} \cdot (1 - S_{AP}) \cdot R_A \cdot [1 - S_{Ap} \cdot R_A + S_{AP}^2 \cdot R_A^2 - S_{AP}^3 \cdot R_A^3 + \cdots] \\ &\cong S_{Ap} \cdot (1 - S_{AP}) \cdot \alpha \cdot \frac{\Delta V_A}{V_{AP}} \cdot \left[1 + \left(\frac{\alpha - 1}{2} - S_{Ap} \cdot \alpha \right) \cdot \left(\frac{\Delta V_A}{V_{AP}} \right) + \cdots \right]. \end{aligned} \tag{A.11}$$

When $|\Delta V_A / V_{AP}|$ is sufficiently small, the infinite series as the correction factor in the bracket on the righthand side of Equation (A.11) is approximately equal to 1, in which case Equation (A.11) is reduced to a linear relationship:

$$\Delta S_A \cong S_{AP} \cdot (1 - S_{AP}) \cdot \alpha \cdot \frac{\Delta V_A}{V_{AP}}. \tag{A.12}$$

Finally, let us consider the situation that competitors have also increased their product value. Then the market share of company A is changed to the following equations, which can be derived in similar fashion as in the equations (A.6)~(A.9).

$$\Delta S_A = S_{AP} \cdot \frac{(1 - S_{AP}) \cdot R_A - \sum_{i=1}^{n-1} S_{ip} \cdot R_i}{1 + S_{AP} \cdot R_A + \sum_{i=1}^{n-1} S_{ip} \cdot R_i}, \tag{A.13}$$

$$R_i \equiv \left(\frac{V_{iN}}{V_{ip}} \right)^{\alpha} - 1, \tag{A.14}$$

$$S_{AN} = S_{AP} \cdot \frac{1 + R_A}{1 + S_{AP} \cdot R_A + \sum_{i=1}^{n-1} S_{ip} \cdot R_i}, \tag{A.15}$$

where R_i = the oriented relative value increment of new product to its current product in the i-th competitor,
S_{ip} = present market share of the i-th competitor,
V_{ip} = current product value of the i-th competitor,
V_{iN} = new product value of the i-th competitor.

REFERENCES

Consumer Union (1998), Ratings Television sets. *Consumer Reports*, 26.

Evans, J.W. and Evans, J.Y. (1997), Reliability Assessment for Development of Microtechnologies. *Microsystem Technologies*, **3**, 149.

Evans, J.W., Evans, J.Y. (2001), *Product Integrity and Reliability in Design*. Springer, 7, 15.

Garvin, David A. (1987), Competing on the Eight Dimensions of Quality. *Harvard Business Review*, 101-109.

Gale, Bradley T. (1994), *Managing Customer value*. the Free Press, 29, 82, 128, 179.

IEEE Reliability Society (1998), IEEE Standard Methodology for Reliability Prediction and Assessment for Electronic Systems and Equipment. *IEEE Std 1413*, 4.

Ryu, Dongsu (1999), *Technology Innovation*. Seoul, Hanseung, Appendix 2, Appendix 5, Appendix 6.

Ryu, Dongsu and Choi, Hoonki (1999), A Study on the Tone Reproduction Optimization of C/TV. *Proc. of the Optical Society of Korea*, 212.

Schnaars, Steven P. (1991), *Marketing Strategy*. New York Free Press, 218.

Shin, Kyungseok, and Park, Seongyong, et al. (2001), The development for Quantitative Evaluation Method of Product Design, *Korean Society of Consumer Studies Journal.*

Swink, Morgan L. (1996), Customizing Concurrent Engineering Process: Five Case Studies. *Journal of Product Innovation Management*, 234.