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Getting the Quality and Reliability Terminology Straight

Soon-Bok Lee, Asaf Katz, and Craig Hillman
CALCE Electronic Products and Systems Center
University of Maryland,
College Park, MD 20742
http://www.calce.umd.edu

Failures are often due to a complex set of stochastic interactions between the loads that act on a product and the various elements (design, components, materials, software, human interface) that comprise the product. Preventing failures by understanding and improving product quality and reliability are sometimes hindered by the misapplication of important terminology. The intent of this article is to reduce this miscommunication by defining some of the key vocabulary in the field of quality and reliability and explaining their appropriate use and misuse.

1. Quality

Quality refers directly to the components and assembly, not performance, of the product and is usually defined as the degree of conformance to applicable specifications or workmanship criteria. Higher *quality* products will tend to lead to improvements in *integrity* and *reliability*, but the three terms are not synonymous. W. Edwards Deming noted: *"The difficulty in defining quality is to translate future needs of the user into measurable characteristics, so that a product can be designed and turned out to give satisfaction at a price that the user will pay. This is not easy, and as soon as one feels fairly successful in the endeavor, he finds that the needs of the consumer have changed, competitors have moved in, there are new materials to work with, some better than the old ones, some worse; some cheaper than the old ones, some dearer"* [1].

Although it is commonly accepted that customer satisfaction is the ultimate measure for quality, customer satisfaction is an integration of many factors, not constant and not easily measured. Franklin Nash [2] has found that, "*The dimensions of quality include reliability, initial performance, features, conformance to specifications, durability, serviceability, ease of use, reputation (perceived quality), safety, environmental compatibility, and, in an expanded view, may include cost and on-time delivery*.

2. Integrity and Reliability

Integrity is defined as the product’s ability to meet some performance specifications the manufacturer is willing to demonstrate. This occurs during qualification, which confirms the integrity by showing nominal operation of the product after being subjected to accelerated testing in harsh conditions. While integrity can be specified by the manufacturer, reliability of a product is application specific and is thus usually defined by the customer.

Reliability is the measure of a products ability to perform a required function under stated conditions for an expected duration. The required function may be described by some output characteristic, such as satisfactory transmission from a communication product, the accuracy of weather identification by airborne radar, or the cleanliness of clothes from a washing machine. The stated condition might be a non-stablized power supply, stormy weather, or boiling wash water. The expected duration may be in hours, miles, or the number of wash and dry cycles. Thus, by definition, reliability is an *application specific* term. Consider a transmitter in a mobile phone, which worked well for the guaranteed three years, and a similar transmitter in a communication satellite that carried out the same function for ten years, as specified. Both have the same *reliability*, having satisfied the customer expectations, even though in some aspects the *integrity* of the transmitter in the mobile phone may be far below that of the satellite transmitter.

3. Loads and stresses

A load is a condition that induces a stress on a product. Loads can be steady, transient, cyclic, and random sequences of mechanical, thermal, electrical, chemical, and radiation conditions. Stress is defined as the intensity of the product’s reaction to these loads. Stress is a function of the design, materials, and fabrication quality of the product, and its load. The stress-to-strength ratio and reliability are antipodes - high stress- to-strength ratio tends to result in low reliability, while high reliability claims low stresses, relative to the product strength.

4. Failures, Failure Modes, Failures Mechanisms and Failures sites

A failure is any unwanted or disappointing behavior of a product. It can include a car that does not start, a toy that has a faded color, a student who believes 7+7=2, or a computer that fails to recognize its hard disk.

A failure mode is defined as the effect by which a failure is observed. Failure modes can be electrical (open or short circuit, stuck at high), physical (loss of speed, excessive noise), or functional (loss of power gain, communication loss, high error level).

Failure mechanism refers to the processes by which the failure modes are induced. It includes physical, mechanical, electrical, chemical, or other processes and their combinations. Knowledge of failure mechanism provides insight into the conditions that precipitate failures.

A failure site describes the physical location where the failure mechanism is observed to occur, and is often the location of the highest stresses and lowest strengths. Table 1 exhibits some simple failures and their relative modes, mechanisms and sites.

Table 1 - Failures, Failure Modes, Failure Mechanisms, and Failure Sites

Failure	**Failure mode**	**Failure Mechanism**	**Failure Site**
Car does not start	Starter motor does not run	Corroded relay contacts	Main contact of starter relay
Toy has faded color	Color changes from red to pink	Accumulation of high UV dose	Red plastic leg

7+7=2	Student writes 7+7=2 in his notebook	Student is short-sighted, cannot differ 7 from 1	Student eyes
Hard disk failure	Computer has no access to hard disk	Hard disk address is 11 instead of 12	Line 87 in the hard disk driver software

Inability to distinguish failure mode, failure mechanism, and failure site can frustrate attempts at successful failure analysis. An example was recently seen when an automobile parts manufacturer's attempted to conduct failure characterization on warranty returns. By placing failure modes (e.g., no high speed), failure sites (e.g., cracked solder joints), and failure mechanisms (e.g., relay bent during manufacture) in the same grouping scheme, their attempt to identify the major causes of warranty returns was rendered ineffectual and a waste of critical time and manpower.

5. Failure Analysis

The purpose of failure analysis is to find the root-cause of what, why, how, and where products can fail. The "what" is associated with the failure mode and the "why" and "how" with failure mechanisms. The "where" is the failure site. In performing failure analysis, the following questions should be addressed:

- What can happen? What are the specific failure modes?
- What are the potential failure mechanisms, and causes (load, stress)?
- Where can it happen? Where are the potential failure sites?
- When and how can it happen? What are the specific failure conditions?

If the failure analysis is being conducted because of a failure, corrective actions should be identified to avoid similar failures in the future. Corrective actions should then be integrated into the reliability improvement plan and procedures.

6. Conceptual Models for Failure

Products will fail if and when the stress exceeds the product’s strength. The applied stress is usually expressed as a normal random distribution, with the mean and standard deviation estimated from a stress analysis that includes the effects of environmental loads, tolerances, geometry and material property variability at the failure site. Strength is also assumed to be a normal random distribution, based on the mean and scatter of the damage property at the failure site. The areas where the stress overlaps the strength of the material are assumed to sites of field failure (Figure 1). If the stress does not exceed the strength and has no permanent effect, the product is assumed to be good as new.

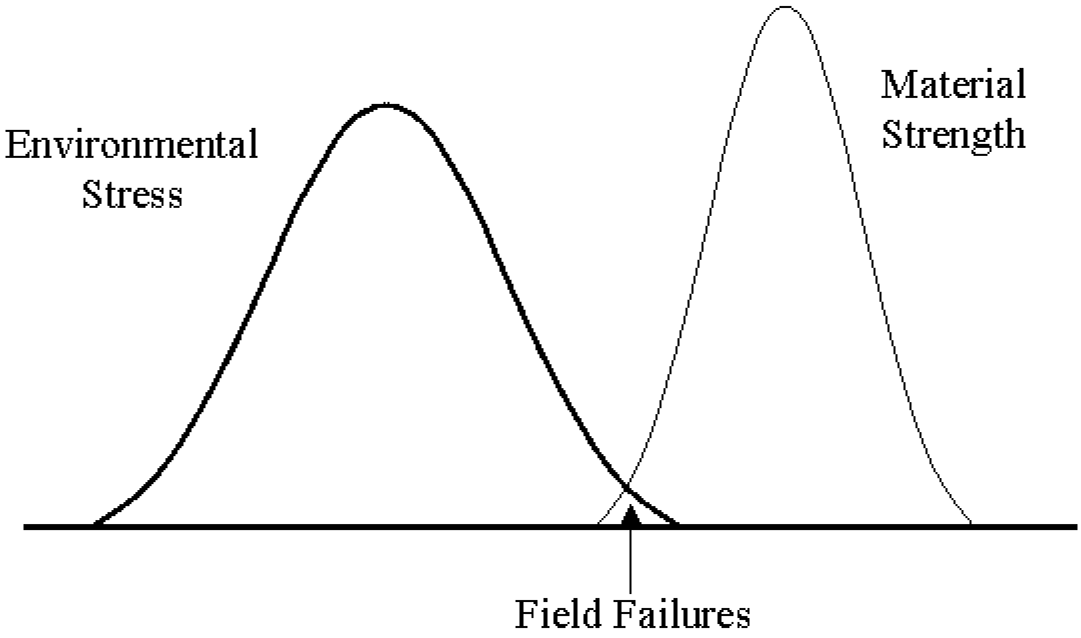

Figure 1: Overlap of the normal distributions of environmental stress and material strength leads to failures in the field.

Some stresses cause damage that accumulate irreversibly, as in corrosion, wear, fatigue, and dielectric breakdown. The item will then fail when the accumulated damage exceeds the endurance of the product. Accumulated damage does not disappear when the stresses are changed although sometimes "annealing" is possible. Reliability can then be defined as either the probability that the strength exceeds stress for all possible stress values in the distribution or the expected duration at which point the accumulated damage exceeds the endurance of the product.

Table 2 lists some generic failure mechanisms, grouped in two categories, according to the type of resulting failure. Catastrophic failures due to a single occurrence of a stress event that exceeds the intrinsic strength of the material are termed overstress mechanisms. Failures due to the accumulation of incremental exceeding the endurance of the material are termed wear-out mechanisms.

Table 2 - Common Failure Mechanisms of MicroElectronics

Overstress failure mechanisms when a single stress excursion exceeds strength	Wear-out failure mechanisms when accumulated damage exceeds endurance
Mechanical • Fracture • Buckling • Yielding *Electrical*	*Mechanical* • Fatigue • Creep • Corrosion *Electrical*

Fused or shorted wires Electrostatic discharge Electrical overstress *Thermal* Melting *Physical/Chemical* Crystal lattice defects due to ionizing radiation	Leakage current Metal migration Threshold voltage shift *Thermal* Elasticity degradation *Physical/Chemical* Interdiffusion Depolymerization

7. "Random" Failures

It is usually necessary to quantify our ignorance of the stresses, product/elements, and other variables involved in failure mechanisms, by using stochastic (random) distributions and processes to represent and simulate them and their behavior. However, it is wise to avoid the phrase, "random failure" because it is often misunderstood and/or misused to mean "without cause".

8. Mean Time-Between Failures

The phrase Mean-Time-Between-Failures (MTBF) virtually always implies a Poisson process (constant failure intensity) when it is used in a reliability context, especially in an engineering specification. While the term MTBF, also known colloquially as "average lifetime", is uniquely defined, few people are aware of its true connotation. In fact, business is often conducted on the basis of advertisements of average lifetime without manufacturers or customers realizing what it means. Most people believe that MTBF is a *minimum* operating lifetime. That is, an average lifetime, but with very small scatter, especially on the early-failure side. A car with an advertised MTBF of 10 years is often expected by the consumer to operate reliably for a *minimum* of 10 years.

An illustration of how even knowledgeable people can misunderstand MTBF is seen in a column published in the weekly *Electronic News* in September of 1988. The author berated a US military request-for-quotation that required a MTBF of 77 years for a radio controller. One of his questions was, "Why, with electronic technology leapfrogging to a new generation every 3 years, would you want a radio controller with a 77-year lifetime?" If he misunderstood the implications of MTBF just think how often a congressman, general, company president or your boss misunderstands it. A much clearer term is *failure rate* – or *failure intensity* for the purists. The failure rate, simply the mathematical reciprocal of MTBF, receives greater comprehension by most people because they deal with it on a regular basis as a measure of returns or warranties. A 77-year MTBF translates to an average failure rate of 1.3% per year – which is what the military really meant in the first place.

The cost of misunderstanding reliability terminology is displayed in an example where a pacemaker manufacturer informed doctors that the battery in their product had an *average lifetime* of four years [3]. The doctors therefore told their patients that the batteries would last four years. However, the probability of failure during a MTBF, or average lifetime, period is defined as 63%. As might be expected, a high percentage of the patients found that their batteries failed before four years, sometimes in as little as six months. Since the batteries did not give advance warning of failure, some patients died. As a result of this confusion over simple reliability terminology, a number of patients sued their doctors and in turn the doctors sued the manufacturer.

Today, there is no market for a product with a 63% mean chance of failure during its "average lifetime". Products are expected to operate for many years and even 0.1% of the products failing in a reasonable time period can result in extensive losses for the manufacturer. Knowing only the average lifetime is no longer of prime importance. The dispersion around the average lifetime, defined by the standard deviation, must also be taken into account.

9. Summary

Our daily life is a combination of operating and use complex and integrated machines that incorporate many technologies and know-how. Many of them are results of worldwide design and production efforts. The quality and reliability of a product is not a matter of chance. It is instead a rational consequence of a conscious, productatic, and rigorous team effort at every stage of design, development, manufacturing, use and maintenance.. Constant efforts must be made to debug, improve and upgrade knowledge, components, products, and communication. By standardizing common terminology, these efforts can be more effective and the customers can have better products and be better informed.

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4. **Soon-Bok Lee** (S''74-''76) received a Ph.D. degree in Mechanical Engineering from Stanford University, Stanford, Ca in 1980. He is a Professor in the Mechanical Engineering Department at the Korea Advanced Institute of Science and Technology (KAIST), where he conducts research in the area of electronic packaging and electronics reliability issues. Currently he is a visiting professor at the CALCE EPSC. Dr. Lee is a member of KSME (Korea Society of Mechanical Engineers), ASME, IEEE, SEM and has served as an editor of KSME Journal, and a Directorial Board Member of KSME.

5. **Asaf Katz (**M''85) received B.Sc. degree, Cum Laude in Electronics Engineering from the Technion - IIT, Haifa, Israel, in 1969. Since his graduation he has been involved in research, development, design, manufacture and test of high reliability products, mostly in the Ministry Of Defense, Israel. Prior to his current 2 year sabbatical at CALCE EPSC he was head of the Quality and Reliability division of the Electronics Research Department, MOD, Israel, for eleven years. He is a member of IEEE and ISQ.

6. **Craig Hillman** received a B.Sc. degree in the majors of Metallurgical Engineering and Engineering and Public Policy from Carnegie Mellon University. He then went on to receive a Ph.D. in Materials at the University of California-Santa Barbara, in 1996. After spending two

years at Cambridge University in England working on the structural properties, processing, and reliability of ceramics, he joined CALCE EPSC in 1998.