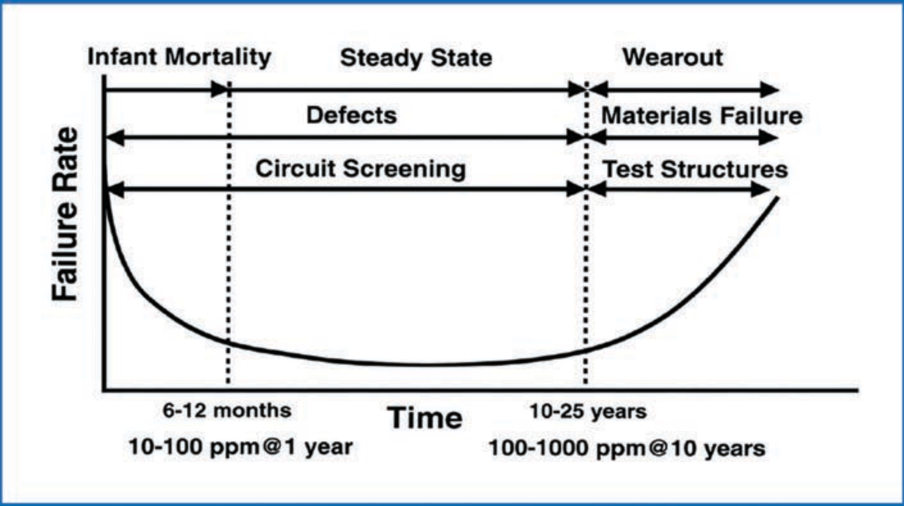

Practical Reliability of Electronic Equipment and Products

Eugene R. Hnatek

CRC Press
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PRACTICAL RELIABILITY OF ELECTRONIC EQUIPMENT AND PRODUCTS

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To my mother Val, my wife Susan, and my Lord and Savior Jesus Christ
for their caring ways, encouragement, and unconditional love.
Words cannot adequately express my gratitude and feelings for them.
To my brother Richard for his loving care of our mother.

Preface

Reliability is important. Most organizations are concerned with fast time to market, competitive advantage, and improving costs. Customers want to be sure that the products and equipment they buy work as intended for the time specified. That's what reliability is: performance against requirements over time.

A number of excellent books have been written dealing with the topic of reliability—most from a theoretical and what I call a ''rel math'' perspective. This book is about electronic product and equipment reliability. It presents a practical ''hands-on perspective'' based on my personal experience in fielding a myriad of different systems, including military/aerospace systems, semiconductor devices (integrated circuits), measuring instruments, and computers.

The book is organized according to end-to-end reliability: from the customer to the customer. At the beginning customers set the overall product parameters and needs and in the end they determine whether the resultant product meets those needs. They basically do this with their wallets. Thus, it is imperative that manufacturers truly listen to what the customer is saying. In between these two bounds the hard work of reliability takes place: design practices and testing; selection and qualification of components, technology and suppliers; printed wiring assembly and systems manufacturing; and testing practices, including regulatory testing and failure analysis.

To meet any reliability objective requires a comprehensive knowledge of the interactions of the design, the components used, the manufacturing techniques employed, and the environmental stresses under which the product will operate. A reliable product is one that balances design-it-right and manufacture-it-correctly techniques with just the right amount of testing. For example, design verification testing is best accomplished using a logical method such as a Shewhart or Deming cycle (plan–do–check–act–repeat) in conjunction with accelerated stress and failure analysis. Only when used in this closed-feedback loop manner will testing help make a product more robust. Testing by itself adds nothing to the reliability of a product.

The purpose of this book is to give electronic circuit design engineers, system design engineers, product engineers, reliability engineers, and their managers this end-to-end view of reliability by sharing what is currently being done in each of the areas presented as well as what the future holds based on lessons-learned. It is important that lessons and methods learned be shared. This is the major goal of this book. If we are ignorant of the lessons of the past, we usually end up making the same mistakes as those before us did. The key is to never stop learning. The topics contained in this book are meant to foster and stimulate thinking and help readers extrapolate the methods and techniques to specific work situations.

The material is presented from a large-company, large-system/product perspective (in this text the words *product*, *equipment*, and *system* are interchangeable). My systems work experiences have been with large companies with the infrastructure and capital equipment resources to produce high-end products that demand the highest levels of reliability: satellites, measuring instruments (automatic test equipment for semiconductors), and high-end computers/servers for financial transaction processing. This book provides food for thought in that the methods and techniques used to produce highly reliable and robust products for these very complex electronic systems can be ''cherry-picked'' for use by smaller, resource-limited companies. The methods and techniques given can be tailored to a company's specific needs and corporate boundary conditions for an appropriate reliability plan.

My hope is that within this book readers will find some methods or ideas that they can take away and use to make their products more reliable. The methods and techniques are not applicable in total for everyone. Yet there are some ingredients for success provided here that can be applied regardless of the product being designed and manufactured. I have tried to provide some things to think about. There is no single step-by-step process that will ensure the production of a high-reliability product. Rather, there are a number of sound principles that have been found to work. What the reader ultimately decides to do depends on the product(s) being produced, the markets served, and the fundamental precepts under which the company is run. I hope that the material presented is of value.

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I want to acknowledge the professional contributions of my peers in their areas of expertise and technical disciplines to the electronics industry and to this book. This book would not have been possible without the technical contributions to the state of the art by the people listed below. I thank them for allowing me to use their material. I consider it an honor to have both known and worked with all of them. I deeply respect them personally and their abilities.

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Noel Donlin, U.S. Army, retired
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Charles Hawkins, University of New Mexico
Michael Hursthopf, Compaq Computer Corporation, Tandem Division
Andrew Kostic, IBM
Edmond Kyser, Compaq Computer Corporation, Tandem Division; now with Cisco Systems
Ken Long, Celestica
Chan Moore, Compaq Computer Corporation, Tandem Division
Joel Russeau, Compaq Computer Corporation, Tandem Division
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Alan Wood, Compaq Computer Corporation, Tandem Division

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Eugene R. Hnatek

Contents

1

Introduction to Reliability

1.1 WHAT IS RELIABILITY?

To set the stage, this book deals with the topic of electronic product hardware reliability. Electronic products consist of individual components (such as integrated circuits, resistors, capacitors, transistors, diodes, crystals, and connectors) assembled on a printed circuit board; third party–provided hardware such as disk drives, power supplies, and various printed circuit card assemblies; and various mechanical fixtures, robotics, shielding, cables, etc., all integrated into an enclosure or case of some sort.

The term *reliability* is at the same time ambiguous in the general sense but very exacting in the practical and application sense when consideration is given to the techniques and methods used to ensure the production of reliable products. Reliability differs/varies based on the intended application, the product category, the product price, customer expectations, and the level of discomfort or repercussion caused by product malfunction. For example, products destined for consumer use have different reliability requirements and associated risk levels than do products destined for use in industrial, automotive, telecommunication, medical, military, or space applications.

Customer expectations and threshold of pain are important as well. What do I mean by this? Customers have an expectation and threshold of pain for the product they purchase based on the price paid and type of product. The designed-in reliability level should be just sufficient enough to meet that expectation and threshold of pain. Thus, reliability and customer expectations are closely tied to price. For example if a four- to five-function electronic calculator fails, the customer's level of irritation and dissatisfaction is low. This is so because both the purchase price and the original customer expectation for purchase are both low. The customer merely disposes of it and gets another one. However, if your Lexus engine ceases to function while you are driving on a busy freeway, your level of anxiety, irritation, frustration, and dissatisfaction are extremely high. This is because both the customer expectation upon purchase and the purchase price are high. A Lexus is not a disposable item.

Also, for a given product, reliability is a moving target. It varies with the maturity of the technology and from one product generation to the next. For example, when the electronic calculator and digital watch first appeared in the marketplace, they were state-of-the-art products and were extremely costly as well. The people who bought these products were early adopters of the technology and expected them to work. Each product cost in the neighborhood of several hundred dollars (on the order of $800–$900 for the first electronic calculator and $200–$400 for the first digital watches). As the technology was perfected (going from LED to LCD displays and lower-power CMOS integrated circuits) and matured and competition entered the marketplace, the price fell over the years to such a level that these products have both become disposable commodity items (except for high-end products). When these products were new, unique, and high priced, the customer's reliability expectations were high as well. As the products became mass-produced disposable commodity items, the reliability expectations became less and less important; so that today reliability is almost a "don't care" situation for these two products. The designed-in reliability has likewise decreased in response to market conditions.

Thus companies design in just enough reliability to meet the customer's expectations, i.e., consumer acceptance of the product price and level of discomfort that a malfunction would bring about. You don't want to design in more reliability than the application warrants or that the customer is willing to pay for. Table 1 lists the variables of price, customer discomfort, designed-in reliability, and customer expectations relative to product/application environment, from the simple to the complex.

Then, too, a particular product category may have a variety of reliability requirements. Take computers as an example. Personal computers for consumer and general business office use have one set of reliability requirements; computers destined for use in high-end server applications (CAD tool sets and the like) have another set of requirements. Computers serving the telecommunication industry must operate for 20-plus years; applications that require nonstop availability and 100% data integrity (for stock markets and other financial transaction applications, for example) have an even higher set of requirements. Each of these

TABLE 1 Key Customer Variables Versus Product Categories/Applications Environment

	Calculators	Personal computers	Pacemaker	Computers for banking applications	Auto	Airline	Satellite
Price	Low	⟶	⟶	⟶	⟶	⟶	Extremely high
Discomfort and repercussion caused by malfunction	Low	⟶	⟶	⟶	⟶	⟶	Extremely high
Designed-in reliability	Low	⟶	⟶	⟶	⟶	⟶	Extremely high
Customer expectations	Low	⟶	⟶	⟶	⟶	⟶	Extremely high

markets has different reliability requirements that must be addressed individually during the product concept and design phase and during the manufacturing and production phase.

Reliability cannot be an afterthought apart from the design phase, i.e., something that is considered only when manufacturing yield is low or when field failure rate and customer returns are experienced. Reliability must be designed and built (manufactured) in from the start, commensurate with market and customer needs. It requires a complete understanding of the customer requirements and an accurate translation of those requirements to the language of the system designer. This results in a design/manufacturing methodology that produces a reliable delivered product that meets customer needs. Electronic hardware reliability includes both circuit and system design reliability, manufacturing process reliability, and product reliability. It is strongly dependent on the reliability of the individual components that comprise the product design. Thus, reliability begins and ends with the customer. Figure 1 shows this end-to-end product reliability methodology diagrammatically.

Stated very simply, reliability is not about technology. It's about customer service and satisfaction and financial return. If a consumer product is reliable, customers will buy it and tell their friends about it, and repeat business will ensue. The same holds true for industrial products. The net result is less rework and low field return rate and thus increased revenue and gross margin. Everything done to improve a product's reliability is done with these thoughts in mind.

Now that I've danced around it, just what is this nebulous concept we are talking about? *Quality* and *reliability* are very similar terms, but they are not interchangeable. Both quality and reliability are related to variability in the electronic product manufacturing process and are interrelated, as will be shown by the bathtub failure rate curve that will be discussed in the next section.

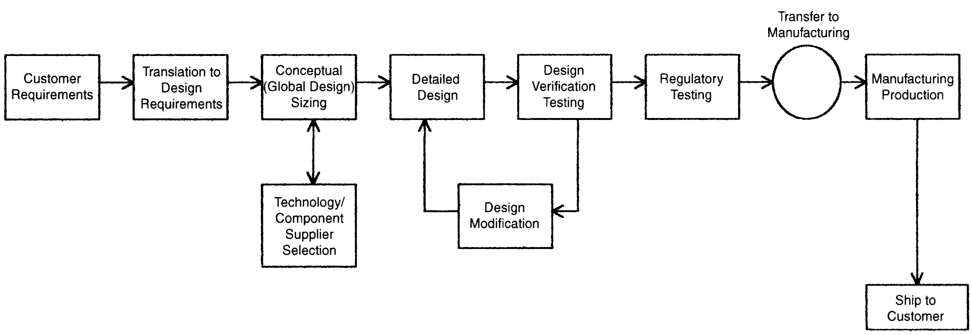

FIGURE 1 End-to-end product reliability.

Quality is defined as product performance against requirements at an instant in time. The metrics used to measure quality include

PPM: parts per million defective
AQL: acceptable quality level
LTPD: lot tolerance percent defective

Reliability is the performance against requirements over a period of time. Reliability measurements always have a time factor. IPC-SM-785 defines reliability as the ability of a product to function under given conditions and for a specified period of time without exceeding acceptable failure levels.

According to IPC standard J-STD-001B, which deals with solder joint reliability, electronic assemblies are categorized in three classes of products, with increasing reliability requirements.

Class 1, or general, electronic products, including consumer products. Reliability is desirable, but there is little physical threat if solder joints fail.
Class 2, or dedicated service, electronics products, including industrial and commercial products (computers, telecommunications, etc.). Reliability is important, and solder joint failures may impede operations and increase service costs.
Class 3, or high-performance, electronics products, including automotive, avionics, space, medical, military, or any other applications where reliability is critical and solder joint failures can be life/mission threatening.

Class 1 products typically have a short design life, e.g., 3 to 5 years, and may not experience a large number of stress cycles. Class 2 and 3 products have longer design lives and may experience larger temperature swings. For example, commercial aircraft may have to sustain over 20,000 takeoffs and landings over a 20-year life, with cargo bay electronics undergoing thermal cycles from ground level temperatures (perhaps as high as 50°C under desert conditions) to very low temperatures at high altitude (about −55°C at 35,000 feet). The metrics used to measure reliability include

Percent failure per thousand hours
MTBF: mean time between failure
MTTF: mean time to failure
FIT: failures in time, typically failures per billion hours of operation

Reliability is a hierarchical consideration at all levels of electronics, from materials to operating systems because

Materials are used to make components.
Components compose subassemblies.

Subassemblies compose assemblies.
Assemblies are combined into systems of ever-increasing complexity and sophistication.

1.2 DISCIPLINE AND TASKS INVOLVED WITH PRODUCT RELIABILITY

Electronic product reliability encompasses many disciplines, including component engineering, electrical engineering, mechanical engineering, materials science, manufacturing and process engineering, test engineering, reliability engineering, and failure analysis. Each of these brings a unique perspective and skill set to the task. All of these need to work together as a single unit (a team) to accomplish the desired product objectives based on customer requirements.

These disciplines are used to accomplish the myriad tasks required to develop a reliable product. A study of 72 nondefense corporations revealed that the product reliability techniques they preferred and felt to be important were the following (listed in ranked order) (1):

Supplier control	76%
Parts control	72%
Failure analysis and corrective action	65%
Environmental stress screening	55%
Test, analyze, fix	50%
Reliability qualification test	32%
Design reviews	24%
Failure modes, effects, and criticality analysis	20%

Each of these companies used several techniques to improve reliability. Most will be discussed in this book.

1.3 THE BATHTUB FAILURE RATE CURVE

Historically, the bathtub failure rate curve has been used to discuss electronic equipment (product) reliability. Some practitioners have questioned its accuracy and applicability as a model for reliability. Nonetheless, I use it for "talking purposes" to present and clarify various concepts. The bathtub curve, as shown in Figure 2, represents the instantaneous failure rate of a population of identical items at identical constant stress. The bathtub curve is a composite diagram that provides a framework for identifying and dealing with all phases of the lives of parts and equipment.

Observations and studies have shown that failures for a given part or piece of equipment consist of a composite of the following:

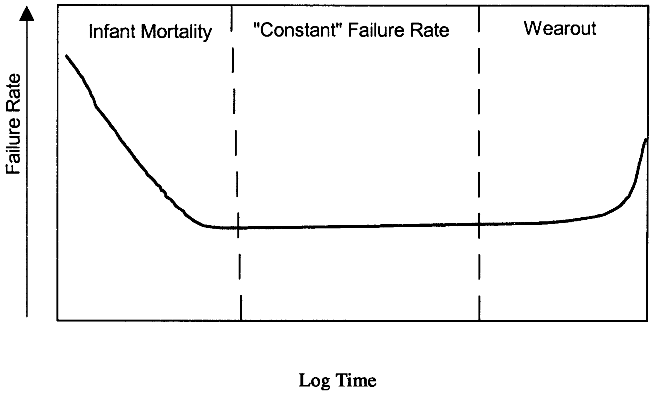

FIGURE 2 The bathtub curve.

Quality	Unrelated to stress Not time-dependent	Eliminated by inspection process and process improvements
Reliability	Stress-dependent	Eliminated by screening
Wearout	Time-dependent	Eliminated by replacement, part design, or new source
Design	May be stress- and/or time-dependent	Eliminated by proper application and derating

The bathtub curve is the sum of infant mortality, random failure, and wear-out curves, as shown in Figure 3. Each of the regions is now discussed.

1.3.1 Region I—Infant Mortality/Early Life Failures

This region of the curve is depicted by a high failure rate and subsequent flattening (for some product types). Failures in this region are due to quality problems and are typically related to gross variations in processing and assembly. Stress screening has been shown to be very effective in reducing the failure (hazard) rate in this region.

1.3.2 Region II—Useful Life or Random Failures

Useful life failures are those that occur during the prolonged operating period of the product (equipment). For electronic products it can be much greater than 10 years but depends on the product and the stress level. Failures in this region are related to minor processing or assembly variations. The defects track with the defects found in Region I, but with less severity. Most products have acceptable

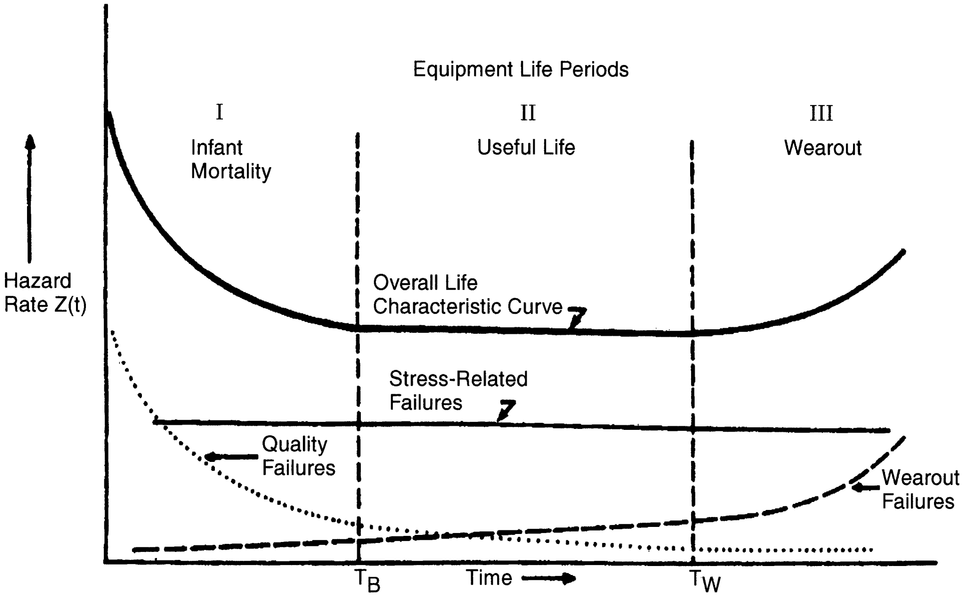

FIGURE 3 The bathtub curve showing how various failures combine to form the composite curve.

failure rates in this region. Field problems are due to "freak" or maverick lots. Stress screening cannot reduce this inherent failure rate, but a reduction in operating stresses and/or increase in design robustness (design margins) can reduce the inherent failure rate.

1.3.3 Region III—Aging and Wearout Failures

Failures in this region are due to aging (longevity exhausted) or wearout. All products will eventually fail. The failure mechanisms are different than those in regions I and II. It has been stated that electronic components typically wear out after 40 years. With the move to deep submicron ICs, this is dramatically reduced. Electronic equipment/products enter wearout in 20 years or so, and mechanical parts reach wearout during their operating life. Screening cannot improve reliability in this region, but may cause wearout to occur during the expected operating life. Wearout can perhaps be delayed through the implementation of stress-reducing designs.

Figures 4–8 depict the bathtub failure rate curves for human aging, a mechanical component, computers, transistors, and spacecraft, respectively. Note that since mechanical products physically wear out, their life cycle failure rate

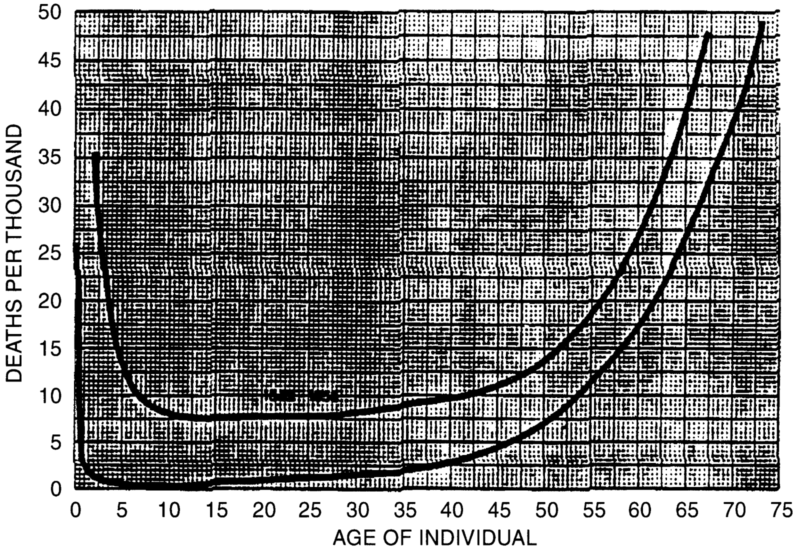

FIGURE 4 Human life cycle curve.

is very different from the electronic product life curve in the following ways: significantly shorter total life; steeper infant mortality; very small useful operating life; fast wearout.

Figure 9 shows that the life curve for software is essentially a flat straight line with no early life or wearout regions because all copies of a software program

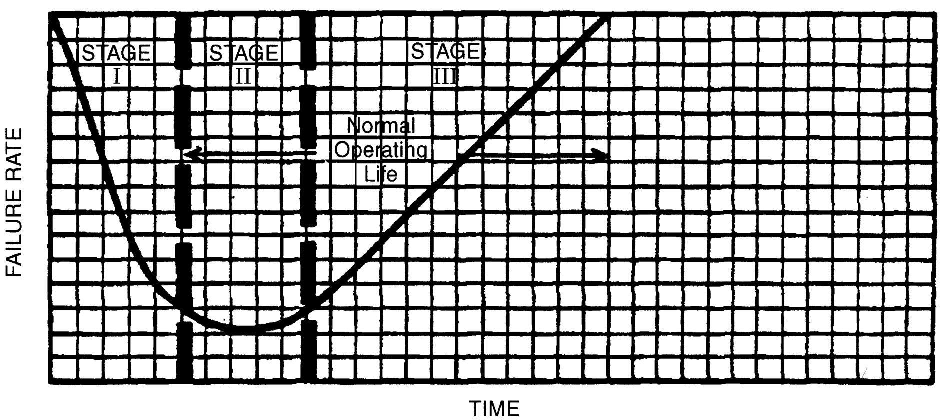

FIGURE 5 Mechanical component life cycle curve.

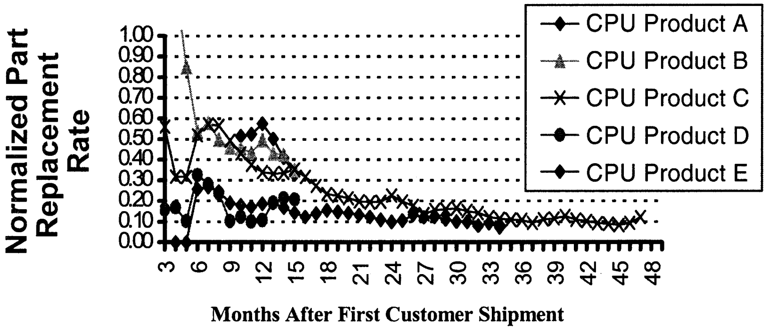

FIGURE 6 Computer failure rate curve.

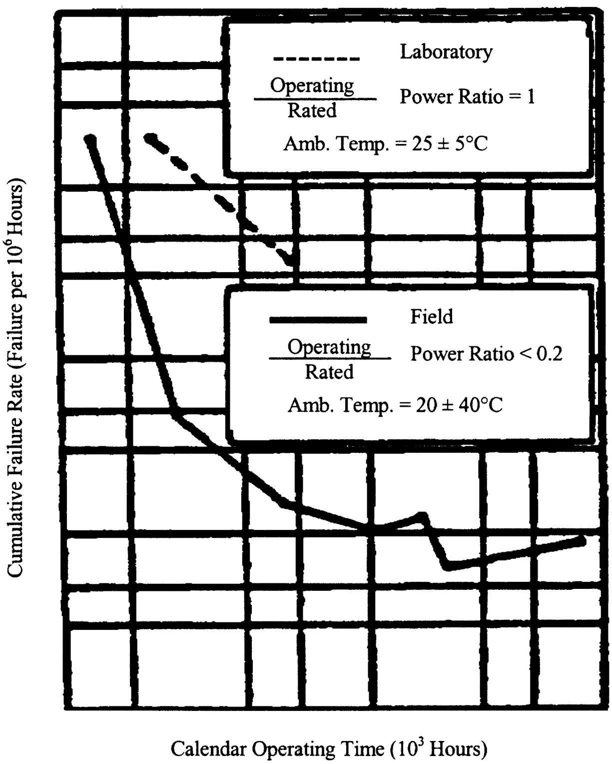

FIGURE 7 Failure rates for NPN silicon transistors (1 W or less) versus calendar operating time.

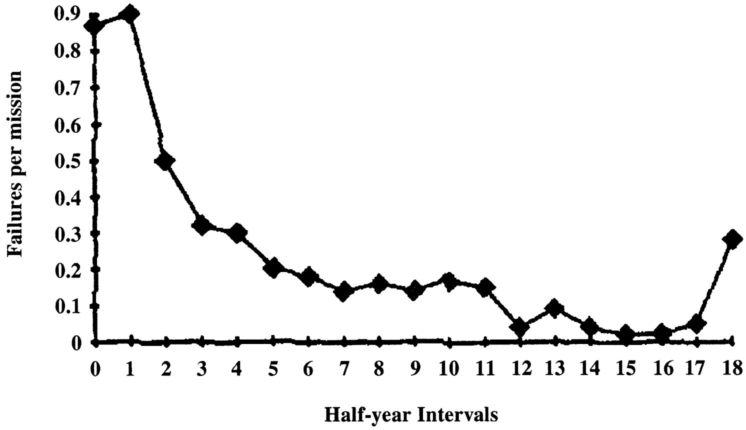

FIGURE 8 Failure rate for spacecraft in orbit.

are identical and software reliability is time-independent. Software has errors or defects just like hardware. Major errors show up quickly and frequently, while minor errors occur less frequently and take longer to occur and detect. There is no such thing as stress screening of software.

The goal is to identify and remove failures (infant mortalities, latent defects) at the earliest possible place (lowest cost point) before the product gets in the customer's hands. Historically, this has been at the individual component level but is moving to the printed wiring assembly (PWA) level. These points are covered in greater detail in Chapters 4 and 7.

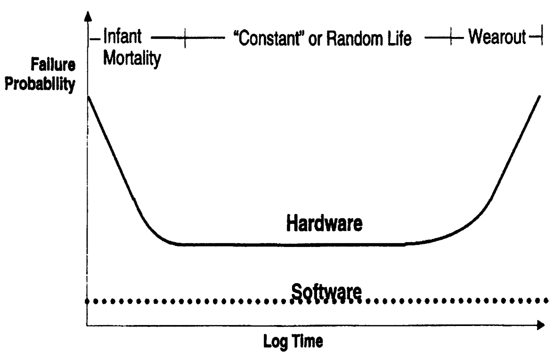

FIGURE 9 Typical software–hardware comparison life curve.

Let me express a note of caution. The bathtub failure rate curve is useful to explain the basic concepts, but for complete electronic products (equipment), the time-to-failure patterns are much more complex than the single graphical representation shown by this curve.

1.4 RELIABILITY GOALS AND METRICS

Most hardware manufacturers establish reliability goals for their products. Reliability goals constrain the design and prevent the fielding of products that cannot compete on a reliability basis. Reliability goals are based on customer expectations and demand, competitive analysis, comparisons with previous products, and an analysis of the technology capability. A combined top-down and bottom-up approach is used for goal setting and allocation. The top-down approach is based on market demand and competitive analysis. Market demand is measured by customer satisfaction surveys, feedback from specific customers, and the business impact of lost or gained sales in which hardware reliability was a factor. The top-down analysis provides reliability goals at a system level, which is the customer's perspective.

The bottom-up approach is based on comparing the current product to previous products in terms of complexity, technology capability, and design/manufacturing processes. Reliability predictions are created using those factors and discussions with component suppliers. These predictions are performed at the unit or board level, then rolled up to the system level to be compared with the top-down goals. If they do not meet the top-down goals, an improvement allocation is made to each of the bottom-up goals, and the process is iterated.

However, there is a wide gap between what is considered a failure by a customer and what is considered a failure by hardware engineering. Again, using computers as an example, the customer perceives any unscheduled corrective maintenance (CM) activity on a system, including component replacement, adjustment, alignment, and reboot as a failure. Hardware engineering, however, considers only returned components for which the failure can be replicated as a failure. The customer-perceived failure rate is significantly higher than engineering-perceived failure rate because customers consider no-trouble-found (NTF) component replacements and maintenance activity without component replacement as failures. This dichotomy makes it possible to have low customer satisfaction with regard to product reliability even though the design has met its failure rate goals. To accommodate these different viewpoints, multiple reliability metrics are specified and measured. The reliability goals are also translated based on customer expectations into hardware engineering goals such that meeting the hardware engineering goals allows the customer expectations to be met.

Typical reliability metrics for a high-reliability, high-availability, fault-

TABLE 2 Metric Definitions for a High-Reliability, High-Availability, Fault-Tolerant Computer

Metric	Definition
Corrective maintenance (CM) rate	A corrective maintenance activity such as a part replacement, adjustment, or reboot. CMs are maintenance activities done in a reactive mode and exclude proactive activity such as preventive maintenance.
Part replacement (PR) rate	A part replacement is any (possibly multiple) part replaced during a corrective maintenance activity. For almost all the parts we track, the parts are returned to the factory, so part replacement rate is equivalent to part return rate.
Failure rate	A returned part that fails a manufacturing or engineering test. Any parts that pass all tests are called no trouble found (NTF). NTFs are important because they indicate a problem with our test capabilities, diagnostics, or support process/training.

Note: All rates are annualized and based on installed part population.

tolerant computer are shown in Table 2. The CM rate is what customers see. The part (component) replacement (PR) rate is observed by the factory and logistics organization. The failure rate is the engineers' design objective. The difference between the failure rate and the PR rate is the NTF rate, based on returned components that pass all the manufacturing tests. The difference between the CM rate and PR rate is more complex.

If no components are replaced on a service call, the CM rate will be higher than the PR rate. However, if multiple components are replaced on a single service call, the CM rate will be lower than the PR rate. From the author's experience, the CM rate is higher than the PR rate early in the life of a product when inadequate diagnostics or training may lead to service calls for which no problem can be diagnosed. For mature products these problems have been solved, and the CM and PR rates are very similar.

Each of the stated reliability metrics takes one of three forms:

CM/PR/failure rate goal, based on market demand
Expected CM/PR/failure rate, based on predictions
Actual CM/PR/failure rate, based on measurement

The relationships among the various forms of the metrics are shown in Figure 10.

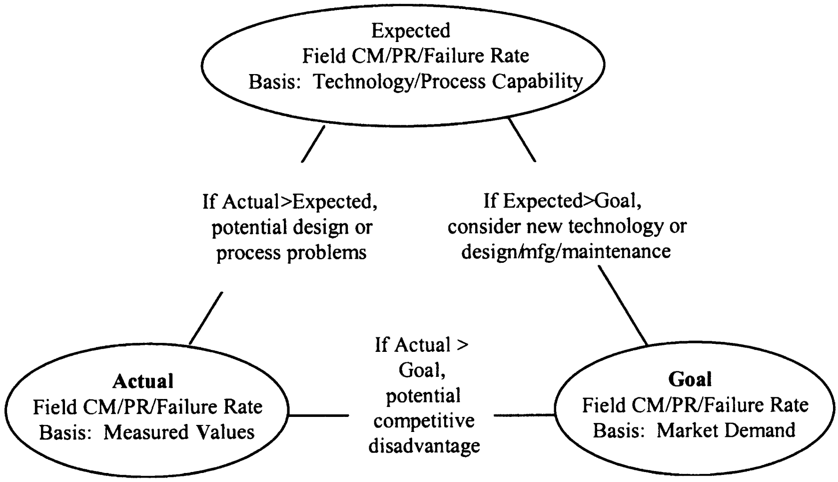

FIGURE 10 Reliability metric forms.

1.5 RELIABILITY PREDICTION

Customers specify a product's reliability requirements. The marketing/product development groups want an accurate quantitative ability to trade off reliability for performance and density. They also may require application-specific qualifications to meet the needs of different market segments. The designers want design for reliability requirements that will not impede their time to market. Manufacturing wants stable qualified processes and the ability to prevent reliability problems. And there is the continuous pressure to reduce the cost of operations.

Reliability modeling assists in calculating system-level reliability from subsystem data and depicts the interrelationship of the components used. Using reliability models, a designer can develop a system that will meet the reliability and system level requirements and can perform tradeoff studies to optimize performance, cost, or specific parameters.

Reliability prediction is performed to determine if the product design will meet its goals. If not, a set of quality initiatives or process improvements are identified and defined such that the goals will be met. Reliability process improvements are justified by relating them directly to improved field reliability predictions.

Reliability prediction is nothing more than a tool for getting a gross baseline understanding of what a product's potential reliability (failure rate) is. The number derived from the calculations is not to be an end-all panacea to the reliability issue. Rather it is the beginning, a call to understand what constitutes reliability for that product and what the factors are that detract from achieving higher reliability. This results in an action plan.

Initial reliability predictions are usually based on component failure rate models using either MIL-HDBK-217 or Bellcore Procedure TR-332. Typically one analyzes the product's bill of materials (BOM) for the part types used and plugs the appropriate numbers into a computer program that crunches the numbers. This gives a first "cut" prediction. However, the failure rates predicted are usually much higher than those observed in the field and are considered to be worst-case scenarios.

One of the criticisms of the probabilistic approach to reliability (such as that of MIL-HDBK-217) is that it does not account for interactions among components, materials, and processes. The failure rate for a component is considered to be the same for a given component regardless of the process used to assemble it into the final product. Even if the same process is used by two different assemblies, their methods of implementation can cause differences.

Furthermore, since reliability goals are based on competitive analysis and customer experience with field usage, handbook-based reliability predictions are unlikely to meet the product goals. In addition, these predictions do not take into account design or manufacturing process improvements possibly resulting from the use of highly accelerated life test (HALT) or environmental stress screening (ESS), respectively. Table 3 presents some of the limitations of reliability prediction.

Thus, reliability prediction is an iterative process that is performed throughout the design cycle. It is not a "once done, forever done" task. The initial reliability prediction is continually refined throughout the design cycle as the bill of materials gets solidified by factoring in test data, failure analysis results, and

TABLE 3 Limitations of Reliability Prediction

Simple techniques omit a great deal of distinguishing detail, and the very prediction suffers inaccuracy.
Detailed prediction techniques can become bogged down in detail and become very costly. The prediction will also lag far behind and may hinder timely hardware development.
Considerable effort is required to generate sufficient data on a part class/level to report statistically valid reliability figures for that class/level.
Component reliability in fielded equipment is very difficult to obtain due to lack of suitable and useful data acquisition.
Other variants that can affect the stated failure rate of a given system are uses, operator procedures, maintenance and rework practices, measurement techniques or definitions of failure, operating environments, and excess handling differing from those addressed by modeling techniques.

the degree to which planned reliability improvement activities are completed. Subsequent predictions take into account usage history with the component technology, suppliers, and specific component type (part number) as well as field data from previous products and the planned design and manufacturing activities. Field data at the Tandem Division of Compaq Computer Corporation has validated that the reliability projections are more accurate than handbook failure rate predictions.

1.5.1 Example of Bellcore Reliability Prediction

A calculated reliability prediction for a 56K modem printed wiring assembly was made using Bellcore Reliability Prediction procedure for Electronic Equipment, TR-332 Issue 5, December 1995. (Currently, Issue 6, December 1997, is the latest revision of Bellcore TR-332. The device quality level has been increased to four levels: 0, I, II, and III, with 0 being the new level. Table 4 describes these four levels.) Inherent in this calculation are the assumptions listed in Table 5.

Assuming component Quality Level I, the calculated reliability for the PWA is 3295 FITS (fails per 10^9 hr), which is equivalent to an MTBF of 303,481 hr. This failure rate is equivalent to an annual failure rate of 0.029 per unit, or 2.9 failures per hundred units per year. The assumption is made that

Table 4 Device Quality Level Description from Bellcore TR-332 (Issue 6, December 1997)

The device failure rates contained in this document reflect the expected field reliability performance of generic device types. The actual reliability of a specific device will vary as a function of the degree of effort and attention paid by an equipment manufacturer to factors such as device selection/application, supplier selection/control, electrical/mechanical design margins, equipment manufacturing process controls, and quality program requirements.

Quality Level 0 Commercial-grade, reengineered, remanufactured, reworked, salvaged, or gray-market components that are procured and used without device qualification, lot-to-lot controls, or an effective feedback and corrective action program by the equipment manufacturer.

Quality Level I Commercial-grade components that are procured and used without thorough device qualification or lot-to-lot controls by the equipment manufacturer.

Quality Level II Components that meet requirements of Quality Level I plus purchase specifications that explicitly identify important characteristics (electrical, mechanical, thermal, and environmental), lot control, and devices qualified and listed on approved parts/manufacturer's lists.

Quality Level III Components that meet requirements of Quality Levels I and II plus periodic device qualification and early life reliability control of 100% screening. Also an ongoing continuous reliability improvement program must be implemented.

TABLE 5 56K Modem Analysis Assumptions

An ambient air temperature of 40°C around the components (measured 0.5 in. above the component) is assumed.
Component Quality Level I is used in the prediction procedure. This assumes standard commercial, nonhermetic devices, without special screening or preconditioning. The exception is the Opto-couplers, which per Bellcore recommendation are assumed to be Level III.
Electrical stresses are assumed to be 50% of device ratings for all components.
Mechanical stress environment is assumed to be ground benign (GB).
Duty cycle is 100% (continuous operation).
A mature manufacturing and test process is assumed in the predicted failure rate (i.e., all processes under control).
The predicted failure rate assumes that there are no systemic design defects in the product.

there are no manufacturing test, or design problems that significantly affect field reliability. The results fall well within the normal range for similar hardware items used in similar applications. If quality Level II components are used the MTBF improves by a factor of about 2.5. One has to ask the following question: is the improved failure rate worth the added component cost? Only through a risk analysis and an understanding of customer requirements will one be able to answer this question.

	Failure rate (FITS)	MTBF (hr)	Annualized failure rate
Quality Level I	3295	303,481	0.029
Quality Level II	1170	854,433	0.010

The detailed bill-of-material failure rates for Quality Levels I and II are presented in Tables 6 and 7, respectively.

1.6 RELIABILITY RISK

It is important that the person or group of people who take action based on reliability prediction understand risk. Reliability predictions vary. Some of the source of risks include correct statistical distribution, statistical error (confidence limits), and uncertainty in models and parameters.

Reliability metrics revolve around minimizing costs and risks. Four cost elements to incorporate in metrics are

TABLE 6 Reliability Calculation Assuming Quality Level I

ID	Generic name	Item code	Part name	QTY	FR
1.1.54	137240-007	IC-Memory	IC, SRAM,32Kx8,15ns,3.3V,SOJ-2	2	438.8
1.1.89	322078-001	IC-Memory	IC, FEPROM,256Kx8,3.3V,50ns,TSO	1	251.3
1.1.72	194774-001	IC-Analog	IC, SM,V/REG,3.3V,500MA,MAX604	1	155.3
1.1.96	009000-000	IC-Analog	IC, ANALOG, CODEC, MQFP44, LUCE	1	285.8
1.1.71	191952-001	IC-Digital	IC, EEPROM,512x8,24CO4,SOIC	1	198.2
1.1.80	322062-001	IC-Digital	IC, USB uCNTRLR,USS820,48TQFP	1	81.8
1.1.91	322081-001	IC-Digital	IC, DAT PMP,DSP1675T28,128TQFP	1	81.8
1.1.5	106146-099	Resistor	RES, SM,2.4K OHM,1/8W,5%	1	1.5
1.1.6	106146-118	Resistor	RES, SM,15K OHM,1/8W,5%	1	1.5
1.1.9	107263-100	Resistor	RES, SM,2.7K OHM,1/4W,5%	1	1.5
1.1.10	107263-111	Resistor	RES, SM,7.5K OHM,1/4W,5%	1	1.5
1.1.20	114740-238	Resistor	RES, SM,24.3 OHM,1%,1/10W,0805	2	3.0
1.1.23	119200-530	Resistor	RES, SM,20.0k OHM, 1/4W, 1%	2	3.0
1.1.29	119919-001	Resistor	RES, SM,0 OHM,1/16W,5%,0603	4	6.0
1.1.30	119919-034	Resistor	RES, SM 4.7 OHM,1/16W,5%,0603	1	1.5
1.1.31	119919-054	Resistor	RES, SM,33 OHM,1/16W,5%,0603	1	1.5
1.1.32	119919-070	Resistor	RES, SM,150 OHM,1/16W,5%,0603	4	6.0
1.1.34	119919-082	Resistor	RES, SM,470 OHM,1/16W,5%,0603	5	7.5
1.1.35	119919-086	Resistor	RES, SM,680 OHM,1/16W,5%,0603	1	1.5
1.1.36	119919-090	Resistor	RES, SM,1K OH,1/16W,5%,0603	1	1.5
1.1.37	119919-094	Resistor	RES, SM,1.5K OHM,1/16W,5%,0603	1	1.5
1.1.38	119919-097	Resistor	RES, SM,2K OHM,1/16W,5%,0603	1	1.5
1.1.39	119919-102	Resistor	RES, SM,3.3K OHM,1/16W,5%,0603	1	1.5
1.1.40	119919-112	Resistor	RES, SM,8.2K OHM,1/16W,5%,0603	1	1.5
1.1.41	119919-114	Resistor	RES, SM,10K OHM,1/16W,5%,0603	2	3.0
1.1.42	119919-134	Resistor	RES, SM,68KOHM,1/16W,5%,0603	1	1.5
1.1.43	119919-138	Resistor	RES, SM,100K OHM,1/16W,5%,0603	4	6.0
1.1.48	124637-013	Resistor	RES, SM,39 OHM,1W,5%	1	1.5
1.1.55	139708-001	Resistor	RES, SM,100 OHM,1%,1/16W,603	1	1.5
1.1.56	139708-006	Resistor	RES, SM,10K,1%,1/16W,603	18	27.0
1.1.57	139708-015	Resistor	RES, SM,191 OHM,1%,1/16W,603	2	3.0
1.1.58	139708-045	Resistor	RES, SM,34.0K,1%,1/16W,603	2	3.0
1.1.59	139708-096	Resistor	RES, SM,475 OHM,1%,1/16W,603	2	3.0
1.1.60	139708-133	Resistor	RES, SM,33.2k,1%,1/16W,603	2	3.0
1.1.61	139708-135	Resistor	RES, SM,16.2k,1%,1/16W,603	2	3.0
1.1.62	139708-170	Resistor	RES, SM,1.30K,1%,1/16W,0603	1	1.5
1.1.63	139708-194	Resistor	RES, SM,26.1K,1%,1/16W,0603	2	3.0
1.1.1	105077-157	Capacitor	CAP, SM,.047MFD,50V,5%,X7R	1	3.0
1.1.2	105077-163	Capacitor	CAP, SM,50V,X7R,5%,.15uF,1812	2	6.0
1.1.3	105079-236	Capacitor	CAP, SM,820PF,50V,10%,NPO	2	6.0
1.1.14	109764-013	Capacitor	CAP, SM,1MFD,20V,20%,TANT	1	3.0
1.1.15	109764-017	Capacitor	CAP, SM,4.7MFD,20V,20%,TANT	1	3.0
1.1.22	117467-726	Capacitor	CAP, 22MFD,35V ALEL	2	246.0
1.1.25	119917-115	Capacitor	CAP, SM,15pF,5%,50V,COG,603	2	6.0
1.1.26	119917-118	Capacitor	CAP, SM,27pF,5%,50V,COG,603	4	12.0
1.1.27	119917-121	Capacitor	CAP, SM,47pF,5%,50V,COG,603	2	6.0
1.1.45	119949-001	Capacitor	CAP, SM,22uf,35V,20%	3	9.0

Table 6 Continued

ID	Generic name	Item code	Part name	QTY	FR
1.1.46	119949-003	Capacitor	CAP, SM,10uF,16V,20%,ALEL	5	225.0
1.1.50	129621-012	Capacitor	CAP, SM,CER,Y5V,0.1uF,16v,0603	32	96.0
1.1.51	129621-021	Capacitor	CAP, SM,CER,Y5V,10uF,35V,1210	1	3.0
1.1.52	129633-201	Capacitor	CAP, SM,25V,10%,0.015,0603	1	3.0
1.1.73	198183-002	Capacitor	CAP, SM,.47UF,X7R,250V,1825	1	3.0
1.1.83	322066-001	Switch	SWITCH, PUSH-PUSH,PB,THRU/HOLE	1	45.0
1.1.85	322068-001	Relay	IC, SM,SLD ST RLY,2FORMA,400V	1	75.0
1.1.86	322070-001	Relay	IC, SM,PWR SW,1.2A,TPS2041D, SO	1	75.0
1.1.8	106899-016	Connector	CONN, PCB,T/JK,6P,LOW PRO	2	7.2
1.1.82	322065-001	Connector	CONN, USB,4P,T/H,TYPE-B	1	2.4
1.1.4	106125-001	LF Diode	DIODE, SM,GNL PRP...PIN2NC	3	54.0
1.1.17	110118-001	LF Diode	DIODE, SM,ZENER,10V	2	36.0
1.1.18	110118-012	LF Diode	DIODE, SM,ZENER,18V	2	36.0
1.1.24	119606-001	LF Diode	DIODE, SM,DUAL,SWITCHING	2	72.0
1.1.67	187108-002	LF Diode	VSTR, SM,275V,250A,2215	1	30.0
1.1.68	187108-005	LF Diode	VSTR, SM,100V,250A,2215	1	30.0
1.1.93	353914-001	LF Diode	DIODE, SM,TVSARRAY,LOWCAP,500W	1	18.0
1.1.11	107269-002	LF Transistor	XSTR, SM,NPN.........MMBTA42	1	18.0
1.1.16	110098-001	LF Transistor	XSTR, SM,PNP,MED PWR......2907	1	18.0
1.1.49	128920-001	LF Transistor	XSTR, SM,NPN,HGH GAIN,MMBT6429	1	18.0
1.1.74	204109-002	LF Transistor	XSTR, SM,DGTL FET,N-CH,25V,.2A	1	60.0
1.1.90	322080-001	LF Transistor	XSTR, NPN,PWR,80V,1.5A,BD139	1	18.0
1.1.92	342615-001	LF Transistor	IC, SM,LD SW,8V,6323L,SSOT-6	1	120.0
1.1.19	110204-005	Optoelec-tronic	DIODE, SM,LED,PURE GREEN,XPRNT	4	36.0
1.1.77	298956-001	Optoelec-tronic	IC, SM,OPTOCPLR,300% CTR	2	54.0
1.1.78	298957-001	Optoelec-tronic	IC, SM,OPTOCPLR,DUAL,300% CTR	1	54.0
1.1.12	107352-009	Inductive	FB, SM,80 OHM,500mA,1806	4	6.0
1.1.13	107352-013	Inductive	FB, SM,600 OHM,200mA,805	2	3.0
1.1.64	141639-001	Inductive	SPKR, XDCR,MINI PCB MMT	1	21.0
1.1.66	176560-001	Inductive	XFMR, MINI,V.32bis	1	12.0
1.1.65	160642-011	Crystal	XTAL, 12.00MHZ,20PF,30PPM	1	75.0
1.1.69	187131-008	Crystal	XTAL, SM,29.4912MHz,20PF,20PPM	1	75.0

1. The cost of a failure in the field
2. The cost of lost business due to unacceptable field failures
3. Loss of revenue due to reliability qualification delaying time to market
4. The cost of the lost opportunity to trade off "excess" reliability safety margins for increased performance/density

Note that the first two items represent a cost associated with failures that occur in a *small subpopulation* of the devices produced. In contrast the last two terms represent an opportunity to increase the profits on *every part* produced. Economic

TABLE 7 Reliability Calculation Assuming Quality Level II

ID	Generic name	Item code	Part name	QTY	FR
1.1.54	137240-007	IC-Memory	IC, SRAM,32Kx8,15ns,3.3V,SOJ-2	2	146.3
1.1.89	322078-001	IC-Memory	IC, FEPROM,256Kx8,3.3V,50ns,TSO	1	83.8
1.1.72	194774-001	IC-Analog	IC, SM,V/REG,3.3V,500MA,MAX604	1	51.8
1.1.96	009000-000	IC-Analog	IC, ANALOG, CODEC, MQFP44, LUCE	1	95.3
1.1.71	191952-001	IC-Digital	IC, EEPROM,512x8,24CO4,SOIC	1	66.1
1.1.80	322062-001	IC-Digital	IC, USB uCNTRLR,USS820,48TQFP	1	27.3
1.1.91	322081-001	IC-Digital	IC, DAT PMP,DSP1675T28,128TQFP	1	27.3
1.1.5	106146-099	Resistor	RES, SM,2.4K OHM,1/8W,5%	1	0.5
1.1.6	106146-118	Resistor	RES, SM,15K OHM,1/8W,5%	1	0.5
1.1.9	107263-100	Resistor	RES, SM,2.7K OHM,1/4W,5%	1	0.5
1.1.10	107263-111	Resistor	RES, SM,7.5K OHM,1/4W,5%	1	0.5
1.1.20	114740-238	Resistor	RES, SM,24.3 OHM,1%,1/10W,0805	2	1.0
1.1.23	119200-530	Resistor	RES, SM,20.0k OHM, 1/4W, 1%	2	1.0
1.1.29	119919-001	Resistor	RES, SM,0 OHM,1/16W,5%,0603	4	2.0
1.1.30	119919-034	Resistor	RES, SM 4.7 OHM,1/16W,5%,0603	1	0.5
1.1.31	119919-054	Resistor	RES, SM,33 OHM,1/16W,5%,0603	1	0.5
1.1.32	119919-070	Resistor	RES, SM,150 OHM,1/16W,5%,0603	4	2.0
1.1.34	119919-082	Resistor	RES, SM,470 OHM,1/16W,5%,0603	5	2.5
1.1.35	119919-086	Resistor	RES, SM,680 OHM,1/16W,5%,0603	1	0.5
1.1.36	119919-090	Resistor	RES, SM,1K OH,1/16W,5%,0603	1	0.5
1.1.37	119919-094	Resistor	RES, SM,1.5K OHM,1/16W,5%,0603	1	0.5
1.1.38	119919-097	Resistor	RES, SM,2K OHM,1/16W,5%,0603	1	0.5
1.1.39	119919-102	Resistor	RES, SM,3.3K OHM,1/16W,5%,0603	1	0.5
1.1.40	119919-112	Resistor	RES, SM,8.2K OHM,1/16W,5%,0603	1	0.5
1.1.41	119919-114	Resistor	RES, SM,10K OHM,1/16W,5%,0603	2	1.0
1.1.42	119919-134	Resistor	RES, SM,68KOHM,1/16W,5%,0603	1	0.5
1.1.43	119919-138	Resistor	RES, SM,100K OHM,1/16W,5%,0603	4	2.0
1.1.48	124637-013	Resistor	RES, SM,39 OHM,1W,5%	1	0.5
1.1.55	139708-001	Resistor	RES, SM,100 OHM,1%,1/16W,603	1	0.5
1.1.56	139708-006	Resistor	RES, SM,10K,1%,1/16W,603	18	9.0
1.1.57	139708-015	Resistor	RES, SM,191 OHM,1%,1/16W,603	2	1.0
1.1.58	139708-045	Resistor	RES, SM,34.0K,1%,1/16W,603	2	1.0
1.1.59	139708-096	Resistor	RES, SM,475 OHM,1%,1/16W,603	2	1.0
1.1.60	139708-133	Resistor	RES, SM,33.2k,1%,1/16W,603	2	1.0
1.1.61	139708-135	Resistor	RES, SM,16.2k,1%,1/16W,603	2	1.0
1.1.62	139708-170	Resistor	RES, SM,1.30K,1%,1/16W,0603	1	0.5
1.1.63	139708-194	Resistor	RES, SM,26.1K,1%,1/16W,0603	2	1.0
1.1.1	105077-157	Capacitor	CAP, SM,.047MFD,50V,5%,X7R	1	1.0
1.1.2	105077-163	Capacitor	CAP, SM,50V,X7R,5%,.15uF,1812	2	2.0
1.1.3	105079-236	Capacitor	CAP, SM,820PF,50V,10%,NPO	2	2.0
1.1.14	109764-013	Capacitor	CAP, SM,1MFD,20V,20%,TANT	1	1.0
1.1.15	109764-017	Capacitor	CAP, SM,4.7MFD,20V,20%,TANT	1	1.0
1.1.22	117467-726	Capacitor	CAP, 22MFD,35V ALEL	2	82.0
1.1.25	119917-115	Capacitor	CAP, SM,15pF,5%,50V,COG,603	2	2.0
1.1.26	119917-118	Capacitor	CAP, SM,27pF,5%,50V,COG,603	4	4.0
1.1.27	119917-121	Capacitor	CAP, SM,47pF,5%,50V,COG,603	2	2.0
1.1.45	119949-001	Capacitor	CAP, SM,22uf,35V,20%	3	3.0

TABLE 7 Continued

1.1.46	119949-003	Capacitor	CAP, SM,10uF,16V,20%,ALEL	5	75.0
1.1.50	129621-012	Capacitor	CAP, SM,CER,Y5V,0.1uF,16v,0603	32	32.0
1.1.51	129621-021	Capacitor	CAP, SM,CER,Y5V,10uF,35V,1210	1	1.0
1.1.52	129633-201	Capacitor	CAP, SM,25V,10%,0.015,0603	1	1.0
1.1.73	198183-002	Capacitor	CAP, SM,.47UF,X7R,250V,1825	1	1.0
1.1.83	322066-001	Switch	SWITCH, PUSH-PUSH,PB,THRU/HOLE	1	15.0
1.1.85	322068-001	Relay	IC, SM,SLD ST RLY,2FORMA,400V	1	25.0
1.1.86	322070-001	Relay	IC, SM,PWR SW,1.2A,TPS2041D, SO	1	25.0
1.1.8	106899-016	Connector	CONN, PCB,T/JK,6P,LOW PRO	2	2.4
1.1.82	322065-001	Connector	CONN, USB,4P,T/H,TYPE-B	1	0.8
1.1.4	106125-001	LF Diode	DIODE, SM,GNL PRP...PIN2NC	3	18.0
1.1.17	110118-001	LF Diode	DIODE, SM,ZENER,10V	2	12.0
1.1.18	110118-012	LF Diode	DIODE, SM,ZENER,18V	2	12.0
1.1.24	119606-001	LF Diode	DIODE, SM,DUAL,SWITCHING	2	24.0
1.1.67	187108-002	LF Diode	VSTR, SM,275V,250A,2215	1	10.0
1.1.68	187108-005	LF Diode	VSTR, SM,100V,250A,2215	1	10.0
1.1.93	353914-001	LF Diode	DIODE, SM,TVSARRAY,LOWCAP,500W	1	6.0
1.1.11	107269-002	LF Transistor	XSTR, SM,NPN.........MMBTA42	1	6.0
1.1.16	110098-001	LF Transistor	XSTR, SM,PNP,MED PWR......2907	1	6.0
1.1.49	128920-001	LF Transistor	XSTR, SM,NPN,HGH GAIN,MMBT6429	1	6.0
1.1.74	204109-002	LF Transistor	XSTR, SM,DGTL FET,N-CH,25V,.2A	1	20.0
1.1.90	322080-001	LF Transistor	XSTR, NPN,PWR,80V,1.5A,BD139	1	6.0
1.1.92	342615-001	LF Transistor	IC, SM,LD SW,8V,6323L,SSOT-6	1	40.0
1.1.19	110204-005	Optoelectronic	DIODE, SM,LED,PURE GREEN,XPRNT	4	12.0
1.1.77	298956-001	Optoelectronic	IC, SM,OPTOCPLR,300% CTR	2	54.0
1.1.78	298957-001	Optoelectronic	IC, SM,OPTOCPLR,DUAL,300% CTR	1	54.0
1.1.12	107352-009	Inductive	FB, SM,80 OHM,500mA,1806	4	2.0
1.1.13	107352-013	Inductive	FB, SM,600 OHM,200mA,805	2	1.0
1.1.64	141639-001	Inductive	SPKR, XDCR,MINI PCB MMT	1	7.0
1.1.66	176560-001	Inductive	XFMR, MINI,V.32bis	1	4.0
1.1.65	160642-011	Crystal	XTAL, 12.00MHZ,20PF,30PPM	1	25.0
1.1.69	187131-008	Crystal	XTAL, SM,29.4912MHz,20PF,20PPM	1	25.0

pressures are going to force increased attention on reliability's role in improving time to market and enhancing performance.

There are two ways to increase the value of reliability predictions. First, rather than a point prediction, the capability is needed to develop curves of reliability levels versus design, manufacturing, and end use variables (Fig. 11). This will allow optimization of the reliability given the economics of a particular marketplace. Second, risk needs to be quantified so it can be factored into technology decisions.

Let's use the bathtub curve to try to answer this question. As mentioned before, the bathtub curve depicts a product's reliability (i.e., failure rate) through-

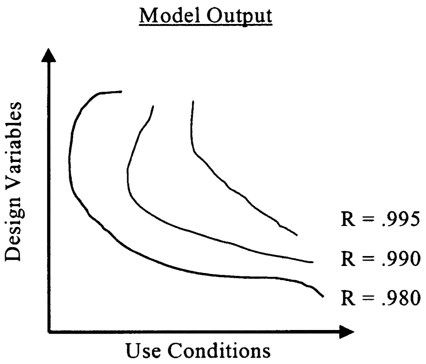

FIGURE 11 Curves of reliability levels as a function of design and use conditions.

out its life. Figure 12 shows the bathtub curve with a vertical line placed at the product's design life requirements. If a high margin exists between the lifetime requirement and the wearout time, a high cost is incurred for having this design margin (overdesign for customer requirements), but there is a low reliability risk. If the wearout portion of the curve is moved closer to the lifetime requirement (less design margin), then a lower cost is incurred but a greater reliability risk presents itself. Thus, moving the onset of wearout closer to the lifetime expected by the customer increases the ability to enhance the performance of all products, is riskier, and is strongly dependent on the accuracy of reliability wearout models. Thus, one must trade off (balance) the high design margin versus cost. Several prerequisite questions are (1) why do we need this design margin and (2) if I

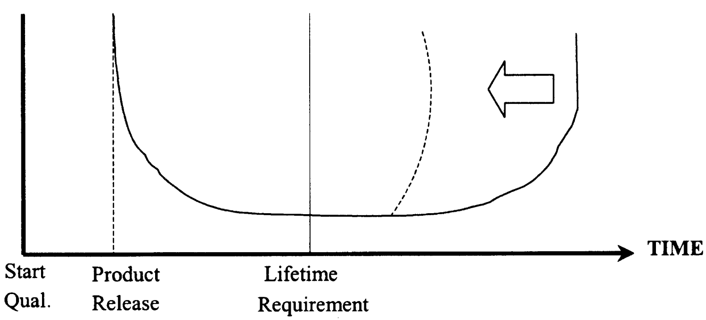

FIGURE 12 Bathtub curve depicting impact of short versus long time duration between product lifetime requirement specifications and wearout.

didn't need to design my product with a larger margin, could I get my product to market faster?

This begs the question what level of reliability does the customer for a given product really need. It is important to understand that customers will ask for very high levels of reliability. They do this for two reasons: (1) they don't know what they need and (2) as a safety net so that if the predictions fall short they will still be okay. This requires that the designer/manufacturer work with the customer to find out the true need. Then the question must be asked, is the customer willing to pay for this high level of reliability? Even though the customer's goal is overall system reliability, more value is often placed on performance, cost, and time to market. For integrated circuits, for example, it is more important for customers to get enhanced performance, and suppliers may not need to fix or improve reliability. Here it's okay to hold reliability levels constant while aggressively scaling and making other changes.

1.7 RELIABILITY GROWTH

Reliability growth is a term used to describe the increase in equipment mean time to failure that comes about due to improvements in design and manufacturing throughout the development, preproduction, and early production phases. The model originally proposed by Duane (3) is probably the most well known for forecasting reliability growth. Since the burn-in process also in effect enhances the reliability, there has been some confusion regarding growth due to corrective actions in design and production, and growth due to burn-in.

Figures 13a and 13b illustrate the separate effects of burn-in and MTTF

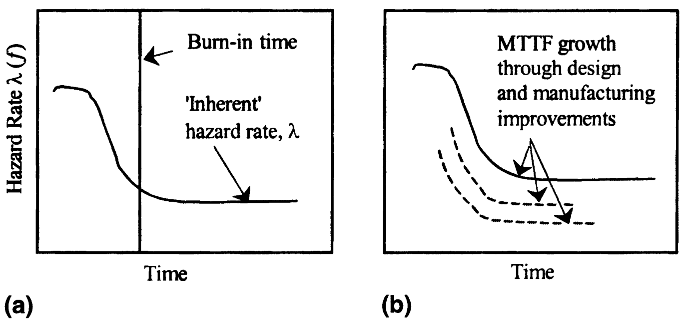

FIGURE 13 (a) Reliability enhancement through burn-in. (b) Reliability enhancement through MTTF growth.

growth. Burn-in removes the weak components and in this way brings the equipment into its useful life period with a (supposedly) constant hazard rate λ (see Fig. 13a). Reliability growth through design and manufacturing improvements, on the other hand, steadily reduces the inherent hazard rate in the useful life period of the product, i.e. it increases the MTTF. The corrective actions we speak of when discussing burn-in are primarily directed toward reducing the number of infant mortality failures. Some of these improvements may also enhance the MTTF in the useful life period, providing an added bonus. The efforts expended in improving the MTTF may very well reflect back on early failures as well. Nonetheless, the two reliability enhancement techniques are independent.

1.8 RELIABILITY DEGRADATION

Degradation can be defined as the wearing down of the equipment through unwanted actions occurring in items in the equipment. An example would be component degradation. Degradation over time slowly erodes or diminishes the item's effectiveness until an eventual failure occurs. The cause of the failure is called the failure mechanism. A graphic example of degradation is the wearing of land by unwanted action of water, wind, or ice, i.e., soil erosion.

Product or equipment reliability degradation can occur due to process-induced manufacturing defects and assembly errors, the variable efficiency of conventional manufacturing and quality control inspection processes, and the latent defects attributable to purchased components and materials. The last has historically caused irreparable problems in the electronics industry and requires that strict process control techniques be used in component manufacturing.

The problem here is the unknown number of latent defects in marginal or weakened components which can fail under proper conditions of stress, usually during field operation.

Some of the things that can be done to prevent reliability degradation are the following:

1. "Walk the talk" as regards quality. This requires a dedication to quality as a way of life from the company president down to the line worker.
2. Implement an effective quality control program at the component, PWA, module, subsystem, and system levels.
3. Design for manufacturing, testability, and reliability.
4. Use effective statistical quality control techniques to remove variability.
5. Implement manufacturing stress screens.
6. Improve manufacturing and test equipment preventative maintenance actions and eliminate poorly executed maintenance.

7. Train the work and maintenance forces at all levels and provide essential job performance skills.
8. Include built-in test equipment and use of fault-tolerant circuitry.

1.8.1 Component Degradation

Component degradation is typically a change which occurs with time that causes the component's operational characteristics to change such that the component may no longer perform within its specification parameters. Operation degradation will occur through the accumulation of thousands of hours of component operation. The component may eventually fail due to wearout. If a component such as a semiconductor device is used within its design constraints and properly manufactured, it will provide decades of trouble-free operation.

Component Degradation Mechanisms

Typical IC degradation mechanisms include

1. Electrical overstress
2. Operation outside of a component's design parameters
3. Environmental overstress
4. Operational voltage transients
5. Test equipment overstress (exceeding the component's parameter ratings during test)
6. Excessive shock (e.g., from dropping component on hard surface)
7. Excessive lead bending
8. Leaking hermetically sealed packages
9. High internal moisture entrapment (hermetic and plastic packages)
10. Microcracks in the substrate
11. Chemical contamination and redistribution internal to the device
12. Poor wire bonds
13. Poor substrate and chip bonding
14. Poor wafer processing
15. Lead corrosion due to improperly coated leads
16. Improper component handling in manufacturing and testing
17. Use of excessive heat during soldering operations
18. Use of poor rework or repair procedures
19. Cracked packages due to shock or vibration
20. Component inappropriate for design requirements

Looking through the list of degradation mechanisms indicates, it is clear that they can be eliminated as potential failure mechanisms resulting in high cost savings. These mechanisms can be eliminated by use of proper component design, manufacturing, and derating processes and by ensuring that the correct component is used in the application.

It is difficult to detect component degradation in a product until the product ceases functioning as intended. Degradation is very subtle in that it is typically a slowly worsening condition.

1.9 RELIABILITY CHALLENGES

Electronics is in a constant state of evolution and innovation, especially for complex products. This results in some level of uncertainty as regards reliability and thus poses challenges. Two of these are as follows:

1. The ratio of new to tried and true portions of electronic systems is relatively high, therefore, reliability information may be largely unknown.
2. There is basically no statistically valid database for new technology that is in a constant state of evolution. Predictions cannot be validated until an accepted database is available.

1.10 RELIABILITY TRENDS

The integration of technology into every dimension of our lives has allowed customers to choose among many options/possibilities to meet their needs. This has led to a raised expectation of customized products. We have come from a one-size-fits-all product and reliability mindset to one of customized products and reliability of manufacturing batches/lots of a single unit. This has increased the number of possible solutions and product offerings.

Product designers and manufacturers have been driven to cut development times; product lifetimes have decreased due to the pace of innovation, and shorter times to market and times to revenue have resulted. Concurrently, the time between early adoption and mass adoption phases for new electronic and digital products has been compressed.

In the past the physical life environment was important in reliability prediction. Today's shortened product life has caused one to question the underlying methodology of the past. What are the concerns of a product that will be produced with an expected life of 18 months or less? A product that could be considered to be disposable? Do we simply toss out the methods that worked in the past, or do we step back and decide which of our tools are the most appropriate and applicable to today's product development and life cycles and customer expectations? In this book various tools and methods are presented that do work for high-end electronic products. It is up to the readers to decide which of the methods presented make sense and should be used in the changing conditions facing them in their own company in their chosen marketplace.

ACKNOWLEDGMENT

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