The Component Failure Myth: Why Electronic System Reliability Cannot Be Predicted by Counting Parts

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Abstract

A long-standing practice in electronic reliability engineering is to estimate system reliability by summing predicted failure rates of electronic components. This approach assumes that system failures are primarily caused by intrinsic component failures and that historical component failure-rate databases can predict future product reliability. This assumption is often unsupported. Modern electronic components, when properly manufactured, selected, derated, assembled, and applied, frequently have an intrinsic life far beyond the system's useful market life. Many field failures instead arise from design-margin deficiencies, circuit misuse, electrical overstress, thermal-mechanical assembly damage, contamination, firmware-hardware interaction, intermittent connections, manufacturing variation, handling damage, and customer-use conditions. Component failure-rate prediction may appear quantitative, but it often assigns numerical precision to mechanisms that are not actually known. A failed component found during failure analysis is not necessarily the root cause of the system failure; it may only be the damaged evidence left behind.

Introduction

For decades, reliability prediction methods such as MIL-HDBK-217, Bellcore/Telcordia, RDF 2000, FIDES, 217Plus, and related databases have encouraged engineers to view reliability as a calculable sum of component failure rates. The typical method is simple: identify each component, assign it a base failure rate, adjust it for stress, temperature, environment, and quality level, and then combine these rates to obtain a predicted system failure rate.

The problem is not that components never fail. They do. The problem is the assumption that intrinsic component failure is the dominant cause of electronic system failure and that historical component failure rates can predict the reliability of a new design. In many real products, the dominant causes of failure are not “parts wearing out.” They are design, process, application, environmental, and operational weaknesses that were not found before release.

This distinction matters. If an organization believes that reliability can be achieved by selecting “better parts” or calculating a lower predicted failure rate, it may miss the actual

weakness in the product. The correct question is not, “What is the predicted failure rate of each component?” The better question is, “What conditions will cause this system, in this application, with this manufacturing variation, software behavior, environment, and user profile, to fail?”

The Hidden Assumption in Component Failure-Rate Prediction

Most component reliability prediction methods begin with a database of historical failure rates. These databases may contain useful information, but their use in new product development requires a large assumption: that the future system will fail by mechanisms similar to the historical population from which the numbers were derived.

That assumption is often weak. A resistor, capacitor, IC, connector, MOSFET, or memory device does not fail in isolation. It exists in a circuit, on a printed wiring board, inside an enclosure, exposed to power transients, thermal gradients, vibration, humidity, contamination, firmware states, manufacturing tolerances, and user behavior. The component is part of an interacting system.

A component may be electrically overstressed because of inadequate transient protection. A capacitor may crack because of board flexure during depaneling. A connector may intermittently open because of vibration, plating choice, contamination, or insufficient normal force. A semiconductor may be damaged by ESD, latch-up, surge current, or an operating condition not represented in the prediction model. A solder joint may become intermittent only under a certain combination of temperature, vibration, and mechanical constraint. These are not intrinsic component life failures. They are system, design, process, or application failures that happen to leave a damaged component behind.

Failed Component Does Not Equal Root Cause

A common failure-analysis error is to identify the damaged component and stop there. For example, a shorted capacitor, a failed MOSFET, an open resistor, or a damaged IC may be found during teardown. The conclusion is then written as “component failure.” But this may only describe the failed item, not the cause.

A MOSFET that failed from avalanche energy, gate overstress, poor layout, or insufficient thermal margin did not fail because its intrinsic life was exhausted. A ceramic capacitor that cracked after board bending did not fail because a reliability database predicted its random failure. An IC damaged by latch-up or ESD did not fail because its long-term wear-out life was reached. In each case, the component is the location of damage, not necessarily the origin of the failure.

This is especially important in modern electronics, where many components have useful intrinsic lifetimes far beyond the product's commercial life. If properly applied, many passive components, semiconductors, and interconnects may last for decades. But if

misapplied, overstressed, poorly assembled, or operated outside realistic design margins, they may fail immediately or intermittently.

MLCC Capacitors: A Useful Example

Multilayer ceramic capacitors are widely used in modern electronic assemblies. They serve as bypass, decoupling, filtering, and transient-suppression components. A typical board may contain hundreds or thousands of MLCCs. A component-count prediction model may treat each capacitor as an independent contributor to the system failure rate.

But MLCC field failures often illustrate the weakness of that assumption. MLCCs are highly reliable when properly selected and used, but they are brittle ceramic devices. They can crack from board flexure, depaneling stress, connector insertion, screw torque, thermal shock, rework, handling damage, or vibration. The resulting defect may not fail immediately. It may become a latent short, a leakage path, an intermittent condition, or a humidity-sensitive failure later in the product's life.

The cause is often not the capacitor's intrinsic dielectric life. The cause may be board layout, capacitor orientation, package size, placement near board edges or connectors, solder profile, mechanical strain, insufficient process control, or lack of strain testing. The reliability solution is not merely to enter a lower capacitor failure rate into a prediction tool. The solution is to understand the stress path and redesign the product or process: change placement, reduce board flexure, use smaller case sizes, add soft-termination capacitors, improve depaneling, control screw torque, or validate strain during manufacturing and service handling.

This example also shows why not every failed component causes a system failure. Many MLCCs are used in parallel for decoupling or transient suppression. One degraded capacitor may have no immediate functional effect. Another, located across a power rail, may short-circuit, disabling the entire system. Component count alone does not capture functional criticality.

System Reliability Is Not the Sum of Component Reliability

A system fails when it no longer performs its required function. That is not the same as saying a component has failed. Some component failures are functionally irrelevant. Some system failures occur with no permanently failed component. Some failures are intermittent and disappear during the depot test. Some are caused by timing margins, noise susceptibility, firmware recovery behavior, power sequencing, or environmental interactions.

This makes simple component summation misleading. It treats components as if they were independent, equally meaningful contributors to system failure. In reality, the effect of a component depends on its function, circuit location, failure mode, detectability, redundancy, stress exposure, and interaction with the rest of the system.

An open bypass capacitor on a noncritical rail may not matter. A cracked capacitor shorted across a primary rail may be catastrophic. A connector with momentary changes in resistance may cause a processor reset, corrupt data, or produce a “no fault found” return. A marginal timing path may work at room temperature but fail at cold or hot limits. A power supply may pass bench tests but oscillate under a real load transient. These failures are not predicted by generic part-count arithmetic.

The Problem with Random Constant Failure Rates

Many traditional reliability prediction models assume a constant failure rate during useful life. This simplifies calculation, but it can hide the actual cause of failure. A constant rate model implies random, independent failures distributed over time. However, many electronic product failures are not random in that sense. They are conditional. They occur when a latent weakness encounters the right stress condition.

A marginal solder joint may fail only during vibration at low temperature. A cracked MLCC may fail after exposure to moisture. A power rail may collapse only during a specific load transient. A high-speed digital interface may fail only when component tolerance, temperature, voltage, firmware timing, and signal integrity combine unfavorably. These are not random intrinsic component life events. They are weaknesses waiting for the correct activation stress.

Reliability improvement, therefore, requires discovery rather than prediction. HALT, HASS, environmental stress screening, design margin testing, overstress testing, root-cause failure analysis, physics-of-failure review, and field-data feedback are better suited to finding these weaknesses than a spreadsheet of generic component failure rates.

Better Questions for Reliability Engineering

Instead of asking, “What is the predicted MTBF?” engineering teams should ask:

1. What are the dominant failure mechanisms for this design, application, environment, and use case?
2. Which circuit functions are most sensitive to component variation, temperature, voltage, vibration, humidity, contamination, and aging?
3. Which components are functionally critical, and which are noncritical or redundant?
4. What are the actual electrical, thermal, mechanical, and environmental stresses seen in use?
5. What assembly or handling steps can damage parts before shipment?
6. What latent defects can pass production test but fail in the field?
7. What failures have similar products experienced, and what verified root causes were found?
8. What margins have been measured, not assumed?

9. What stresses can be applied to reveal weak design or process margins before release?
10. What field-return evidence confirms the real failure mechanism?

These questions shift reliability from prediction to evidence. They also force the organization to distinguish between the failed part and the root cause.

When Component Failure-Rate Data Can Still Be Useful

This article does not argue that component data is valueless. Component failure-rate databases can be useful for rough comparisons, safety calculations, logistics planning, early architectural trade-offs, and identifying historically troublesome technologies. They can also help guide derating, part selection, and supplier risk review.

The problem occurs when these numbers are treated as proof of future product reliability. A calculated MTBF can create false confidence. It may satisfy a contractual requirement while doing little to reveal the weaknesses that will drive real field failures.

Component data should be used as one input, not as the foundation of the reliability program. It should be supplemented by physics-of-failure analysis, design review, circuit stress analysis, derating validation, HALT, HASS, process control, failure analysis, and closed-loop field learning.

Conclusion

The belief that electronic system failures are primarily caused by intrinsic component failure is often unsupported. Modern components, when properly designed into a circuit and protected from excessive electrical, thermal, mechanical, and environmental stresses, often have intrinsic lifetimes longer than the product's useful market life. Many real failures come from how the component is applied, assembled, stressed, controlled, or integrated into the system.

Reliability cannot be assured by counting parts and assigning historical failure rates. A failed component is evidence, not necessarily the root cause. The task of reliability engineering is to discover and remove product weaknesses before customers find them. That requires measured margins, root-cause analysis, physics-of-failure thinking, accelerated stress testing, and field evidence.

The future of electronic reliability engineering should shift from prediction as a compliance exercise to evidence-based reliability: understanding why systems fail, demonstrating where margins exist, and eliminating the root causes of field failures.