Can electronic product reliability be predicted?

Albertyn Barnard, an alumnus of the University of Pretoria and chair of the Reliability Engineering Working Group of the International Council on Systems Engineering, received a silver award for a presentation delivered at the International Applied Reliability Symposium (Europe) held in Warsaw, Poland, in March 2012.

This symposium provides a forum for reliability and maintainability practitioners in industry and government to discuss their success stories and lessons learned regarding the application of reliability techniques to meet real-world challenges. Barnard's presentation examined the question of why one cannot predict electronic product reliability.

According to Barnard, who provides consulting services in systems and reliability engineering in the defence, nuclear, aerospace, utilities and commercial industries, an accurate prediction of the field reliability of an electronic product during the development stage is highly desirable. Reliability prediction methods (and standards) have been developed and applied for many years, and some 'new' standards are constantly introduced. However, when these methods and standards are carefully analysed, they all seem to be based on misleading or even incorrect assumptions.

The implication is that a product is reliable if it does not fail, and that this failure-free state can only be achieved if failure is prevented from occurring. If that is the case, what is required to prevent failures? Firstly, engineering knowledge to understand the applicable failure mechanisms. Secondly, management commitment to mitigate or eliminate failures. The proactive prevention of failure should be the primary focus of reliability engineering, and not reactive failure management or failure correction.

What is reliability prediction?

Reliability prediction is performed during the product development stage, and attempts are made to estimate field reliability. This activity is entirely different from the quantification (or measurement) of reliability during operations.

There are three different approaches to electronic product reliability prediction:

> "All failures in electronic equipment can be attributed to a traceable and preventable cause, and may not be satisfactorily explained as the manifestation of some statistical inevitability." – Norman Pascoe, 2011

What is reliability?

There are two fundamental concepts in reliability engineering. Firstly, that failures are caused, and secondly, that failures can be prevented. Based on these fundamental concepts, and applying common sense to real-life experience, reliability can be defined as the absence of failures, while reliability engineering can be defined as the management function that prevents the creation of failures.

- **Reliability prediction based on published failure data:** This method consists of the calculation of the failure rate for each part in the product (typically as a function of operating temperature). This failure rate is then modified according to factors related to the intended operating environment, the quality of the part or the complexity of the part. These part failure rates

are summed to obtain a product failure rate.
- **Reliability prediction based on practical test:** This method consists of subjecting one or more products (typically prototypes) to a practical step-stress accelerated life test. Analysis of failure data is performed to determine both the time-to-failure distribution and the life acceleration factor. Estimated field reliability is then obtained by extrapolation to the expected 'use' conditions.
- **Reliability prediction based on physics-of-failure:** This method, which was originally developed from research to understand fundamental failure mechanisms, is based on detailed root cause analysis of field or test failures. The knowledge gained from physics-of-failure can then be proactively applied to prevent similar failures in new products.

Why electronic product reliability cannot be predicted based on published failure data

Reliability prediction based on published failure data (also known as standards-based prediction) is usually an exercise in futility.

Reliability prediction based on practical tests and physics-of-failure is much more valuable. However, this is not without its limitations.

If it is possible to predict failures, why not rather prevent failures?

An accurate prediction of reliability implies knowledge of the cause of the failure so that it could be eliminated. If one can predict reliability, that means that one knows what will fail in future. Therefore, why not prevent it from occurring at all?

> "Some well-known documents, such as Mil-Hdbk-217 and derivatives of it, treat all flaws as being precipitated by temperature alone, which is completely erroneous."
> – Gregg Hobbs, 2000

Reliability prediction is contrary to proven wisdom by quality and reliability gurus

Edwards Deming wrote: "Avoid numerical goals. Alternatively, learn the capabilities of processes, and how to improve them." Philip Crosby explained that 'zero defects' is an asymptote (continuous improvement), and Ralph Evans wrote: "The ultimate goal of reliability engineering is surely not to generate an accurate reliability number for the item."

Since all failures are caused by people, why allocate failure rates to parts?

Product failures are primarily caused by errors by design and production personnel, and are generally not caused by defective parts. These errors are due to human nature, and the complexity of engineering. Therefore, why do we allocate failure rates to parts?

Many parts do not have a property such as 'failure rate'

Many items do not have a property such as 'failure rate' (a wine glass, for example, will last forever unless somebody breaks it). Similarly, many electronic parts do not have inherent failure rates, but part failure may be caused by mechanical failure mechanisms, such as environmental conditions specific to the product. Examples include vibration (inferior mechanical design) and temperature (inferior thermal design).

Parts with 'failure rates' may have insignificant failure rates during their useful life

Many electronic products are replaced by customers due to technological obsolescence (for example, computers), and not due to wear-out of parts.

Failure may be caused by software

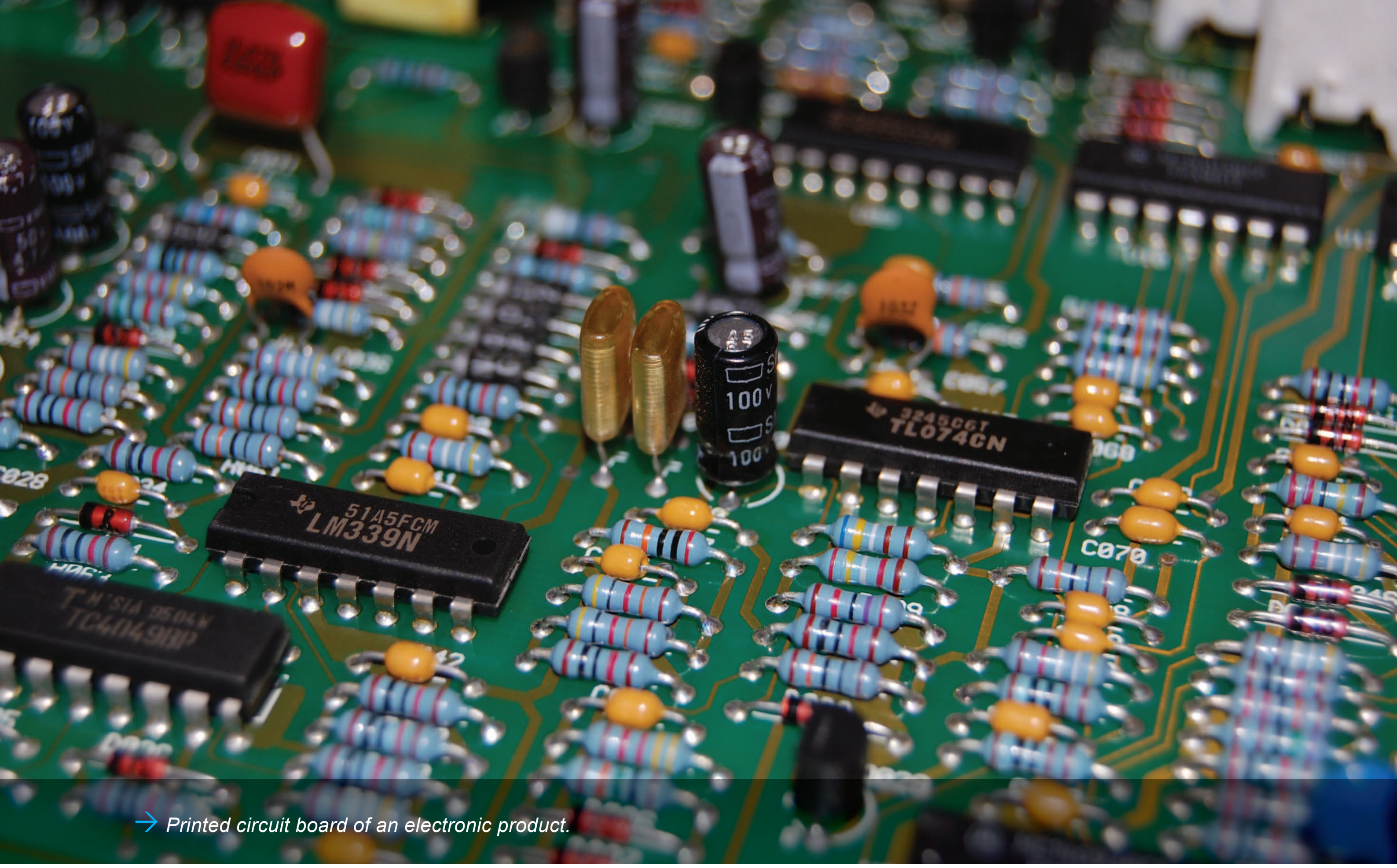
How does one predict embedded software reliability? Available methods are typically based on the complexity of the software, and the number of faults found during testing. However, most prediction methods conveniently ignore software reliability. This is surely inadequate, since most modern electronic products contain one (or many) microcontrollers.

The failure rate of a product is not the sum of the failure rates of its parts

An assumption frequently made in reliability prediction is that the product consists of parts in a series configuration (parts count prediction). This assumption is seldom valid. Furthermore, electronic products may fail due to interaction and integration of good parts (without individual part failure).

All part failures do not have 'constant failure rates'

Many reliability prediction methods assume that the time-to-failure



Printed circuit board of an electronic product.

is exponentially distributed. This assumption is seldom valid, since product failure may be caused by wear-out (fatigue). In fact, many engineers are unaware that mean time between failure (MTBF) should not be used as an indicator of expected life.

Life acceleration factor may be invalid

Mil-Hdbk-217F (and similar databases) assumes an exponential relationship between failure rate and operating temperature, also known as the Arrhenius relationship. Research has shown that this may be invalid for solid-state electronic parts, since the great majority of electronic parts do not suffer from physical or chemical degradation.

Reliability prediction results are frequently unrelated to real-life observations

Due to huge differences in predicted and observed reliability values, companies have proposed modifications to Mil-Hdbk-217F in an attempt to improve the reliability prediction.

Conclusion

Reliability prediction of an electronic product using published failure data is based on many misleading and incorrect assumptions. Many other reliability engineering analyses and test methods should rather be used to identify potential failures modes during development.

For example, part derating analysis can be used to identify electrically or thermally overstressed parts, and highly accelerated life testing (HALT) can be used to identify a range of design and production weaknesses.

Once identified, these potential failure modes can then be corrected prior to full-scale production.

Dr Richard Feynman, Nobel Prize-winning physicist, once said: "It does not make any difference how smart you are, who made the guess, or what his name is – if it disagrees with real-life results, it is wrong. That is all there is to it." This statement may also be applicable to reliability prediction based on published failure data.

__Albertyn Barnard__ received the MEng (Electronics) and MEng (Engineering Management) degrees from the University of Pretoria. He provides training in reliability engineering to industry postgraduates. He has been a member of the management committee of the South African chapter of the International Council on Systems Engineering (INCOSE) for a number of years, and established the INCOSE Reliability Engineering Working Group in 2011. He is currently leading this international working group, which focuses on reliability engineering from a systems engineering viewpoint.