The Journal of Reliability, Maintainability, and Supportability in Systems Engineering

Winter 2019 – Spring 2020

Table of Contents
Winter 2019 – Spring 2020

Editor's Note

John Blyler

Welcome back, readers! You may have noticed that this Winter-2019/Spring 2020 edition of the Journal has been greatly delayed. Several factors contributed to the incompletion of this edition, from personnel issues on the publishing side and interruptions from a new job undertaking on the editorial side, to the general chaos resulting from the beginning of a global pandemic.

Rest assured that the content of the Win-19/Sum-20 edition has not suffered due to the above-mentioned events. Indeed, you'll find the usual balanced blend of industrial viewpoint and technically detailed articles on reliability, maintainability, supportability and logistics that are the hallmark of the Journal.

In this issue, we begin with a query concerning anti-fragile vs. resilience processes. The author raises a new way to view resilient reliable systems.

Next, we look why today's reliability requirements – especially in regulated industries like automotive – may require multiple checks to ensure complete and accurate reliability verification. A packaged check flow is proposed to help designers quickly select, configure and run custom reliability checks and check combinations.

Are you having trouble choosing between a scientific verses administrative approach to reliability? Our third author examines each approach in some detail. I won't spoil the answer by hinting at the results.

Finally, our own Russell Vacante, president of the RMS Partnership, reviews a book: Reliability Prediction and Testing Textbook, by Lev M. Klyatis, Edward L. Anderson. This work focuses on why accurate simulation of real-world conditions is critical to achieve meaningful test results.

I hope you find this issue of value. Please don't hesitate to share your comments and future article with me via email.

Cheers – John
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Is "antifragile" better than "resilient"?

Kurt Cobb

Antifragile" is a word you can't find in the dictionary. Nassim Nicholas Taleb, author and student of probability and risk, coined the word because, after looking at languages across the world, he could not find a word which describes the ability to improve with stress rather than merely resist it as the word "resilient" implies. Antifragile has now become the title of Taleb's latest book. Much of what I am about to say is based on this book.

An obvious example of something that improves with stress is the human body which gets stronger, more fit, and less prone to disease with exercise. Stress, but not too much stress--a cement truck running over you is too much stress--actually improves the performance of the body.

The same is true of the mind. Lying around watching television programs of the innocuous kind that don't challenge anything you believe is unlikely to make you more mentally acute. Difficult problems in life or in mathematics that require careful and prolonged problem-solving can sharpen the mind. Problems in life that cause a mental breakdown may not be good for you unless you come out of the breakdown a new person better prepared for the reality you must cope with--what Taleb informs us is called "post-traumatic growth" in the psychiatric profession.

The word "resilient" is easy to find in the dictionary. And, we should focus carefully on the second definition: "returning to the original form or position after being bent, compressed, or stretched." This seems like a good thing, and to a certain extent it is. Resil-

"If you watch a glacier from a distance, and see the big rocks falling into the sea, and the way the ice moves, and so forth, it is not really essential to remember that it is made out of little hexagonal ice crystals. Yet if understood well enough the motion of the glacier is in fact a consequence of the character of the hexagonal ice crystals. But it takes quite a while to understand all the behaviour of the glacier (in fact nobody knows enough about ice yet, no matter how much they've studied crystal). However, the hope is that if we do understand the ice crystal we shall ultimately understand the glacier."

R. Feynman, "The Character of Physical Law" ient systems, people and societies are good at maintaining their current operation or returning to their previous condition if disturbed.

Now, here's why antifragility rather than resilience might be a better goal for the sustainability movement. Resilience depends, in part, on knowing what kinds of stresses you will be subject to and building up defenses against those stresses. Antifragility does not require that you know what the stresses will be in advance since you expect to be strengthened by them. Again, too much stress will wipe out an antifragile system. But, it will also wipe out a resilient system. So, the added advantage of working toward a state of antifragility is twofold: You will not have to predict all of the stresses you will encounter to prepare for them; and, you will likely benefit from those stresses and so need not be afraid at their approach.

What does this mean in practice? Natural evolutionary strategies are antifragile. Nature tries many, many experiments--many species and subspecies and newly arising species--which increase the chances that some experiments will succeed. Survivability is increased by diversity among plants and animals because as conditions change, some versions will adapt better than others. Here, nature does not know in advance what conditions will prevail, but puts out enough diversity so that some plants and animals will likely survive. So, the antifragility of a system actually depends on some of the parts being fragile.

In business this model is most aptly illustrated by the venture capitalist (VC) who accepts that he or she cannot know in advance which ideas will succeed. So, the VC invests in a great number of fledgling companies knowing that most will fail, but that a few will succeed and flourish so much so that the reward will far outweigh the losses incurred in unsuccessful ventures. Mirroring the process, there are many VCs with varying approaches, philosophies and resources. Some go bust while others thrive. It's the diversity that is important to society.

This is how entrepreneurs perform an important service for the economy. The diversity of startups means many strategies and practices will be tested against the conditions prevailing in the economy and in society. Many will fail, but the few that survive can be a benefit to society.

Now, the specialist knows and does only one thing and can be a company or person. And, the specialist is typically made obsolete or severely impaired in income when conditions change drastically. I worked in the advertising industry just as the changeover from physical artwork to electronic artwork was taking place. Almost overnight designers could now simply type a few commands or perform a few mouse clicks to change the typography in their pieces. Previously, the industry had supported an entire infrastructure of typesetters. Within a short period, the typesetting business was gone.

It's not wrong for people to specialize. In the complex world we live in, most people must do so in order to find employment. And, those employed in typesetting have long since gone on to work at other things. But, we have built huge institutions upon which our society depends for its stability in banking, shipping and manufacturing that are exceedingly fragile. They do not stand up to outsized stresses.

We saw that in 2008 when the banking system, hit by contagion and fear, nearly collapsed which then nearly took out the worldwide logistics system. Sellers feared they might not be paid for goods they were shipping and halted deliveries because bank letters of credit (which were payment guarantees) were not trusted. Alternatively, many

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small failures in the banking system would have been much less consequential. But, a few large failures, because of the interlocking nature of worldwide finance, nearly brought the whole system down.

So, society can benefit from many small failures as they are the path to adaptation telling us what does not work. The successes, of course, give us information about what works, but not necessarily why those strategies worked.

Now, here is the crucial point about making society as a whole antifragile: THE WEAK MUST BE PROTECTED. If the weak are not protected, few people will take the risks necessary to find successful adaptations to the constantly changing social and natural conditions on planet Earth. Instead, most people will become risk averse, fearing that they will become weak and unprotected if they fail. Protecting the weak is entirely the opposite of what reactionary idealogues tells us to do to encourage highly innovative societies.

Another way the weak are protected is when failure does NOT carry with it any stigma. In this respect the United States has a culture that far outpaces most others on the planet. The United States is a place where starting over is not only acceptable, but encouraged, where failure is imagined as a possible gateway to future success--i.e., we believe people learn a lot from failure and recognize that many factors including just plain bad luck can be the cause.

So, the United States gets mixed marks--it does not protect the weak well, but does not stigmatize failure in most cases. Think about where your country rates on these two measures, and it will give you a rough idea if it has the necessary social conditions for antifragility.

Now, you might guess from the previous discussion that size is an important determinate in making a society antifragile. Here is where those advocating for what is often called "relocalization" have a point. Moving the logistics of everyday living from an interlocking worldwide affair to one that is regional or, in some cases, local will have the effect of creating many diverse logistical systems around the globe, each better adapted to the local or regional conditions, and none entirely dependent on a rigid, hyperefficient (and thus fragile) worldwide system that cannot withstand heavy stresses á la 2008.

The other characteristic of an antifragile system is that it will contain buffers, or to put it into logistical terms, it will have inventories--substantial inventories--in case shipments don't always get through in time. In our current system, we believe inventories are bad and try to eliminate them with dangerously fragile just-in-time delivery systems.

In the decentralized system, inventories are a source of strength. Just ask someone who has an ample inventory desperately needed by a region or town. That person will profit from such an inventory while his competitors shut down. And, the people who need the goods will be thankful to get them in a time of instability.

(I confess that the implications here are not entirely savory. The person having the inventory is antifragile in that he or she makes a killing financially when the system breaks down. But, at least the town or region is not left without essential goods and might decide to insure greater antifragility in the future by insisting on greater inventories which then give the whole town or region a competitive advantage. This also might be interpreted as resilience and certainly resilience and antifragility can and do coexist in any economy or society.)

The antifragile idea has so many other implications--for example, a bias toward city-states rather than nation-states--that I cannot catalogue them here. For that you should start with Taleb's Antifragile: Things that Gain from Disorder and see where your imagination takes you.

Reprinted with permission from "Resource Insights", http://resourceinsights.blogspot.com/2013/11/is-antifragile-better-than-resilient.html

Hossam Sarhan

Pick a Package of Reliability Checks for Consistent, Accurate Verification

Today's complex reliability requirements may require multiple checks to ensure complete and accurate reliability verification. Using a packaged checks flow lets designers quickly select, configure and run custom reliability checks and check combinations to help design companies achieve today's demanding time-to-market schedules while ensuring product reliability.

Introduction

How often do you actually think about product reliability? Probably only when you're purchasing a product that is relatively expensive, by your standards. But truthfully? Most of us simply expect product reliability. We expect the lights to go on when we press a switch, we expect our cars to run properly, we expect planes to fly. Most of the time, we as consumers only think about product reliability when it fails our expectations. That's only possible because the people who design and manufacture products start thinking about reliability from the first sketch on a napkin. In the semiconductor industry, the increasing use of electronics in such fields as transportation, medical devices, and communications has exponentially increased the demand for integrated circuits (ICs) that will perform as intended throughout their designed product life.

However, while the need for accurate, precise, and extensive reliability verification has grown significantly, integrated circuit (IC) design companies have encountered major challenges ensuring this enhanced level of IC reliability with traditional verification techniques. Technology scaling combined with the rapid growth in different types of design applications has increased both the number of reliability checks required and their complexity, creating the need for an accurate, automated methodology for reliability verification that can quickly and accurately analyze complex reliability conditions.

All major foundries now provide reliability rule decks that verify selected reliability aspects of IC design, based on those reliability issues they have determined are most critical to their customers [1-8]. Coverage can range from electrostatic discharge (ESD), electrical overstress (EOS), and latch-up (LUP) protection, to interconnect reliability, power management, and other potential reliability impacts. These foundry rule decks provide a solid reliability baseline, and design companies should consider the foundry deck to be a firstline reference when evaluating overall reliability. These decks also provide designers insight into what the foundry considers critical for sign-off criteria.

In addition to their foundry's baseline, every design company typically has additional reliability requirements based on the unique needs and uses of their products. Today's short design cycle encourages companies to complement foundry reliability flows with additional custom checks based on their products' applications to ensure a thorough verification of all essential reliability requirements for their intended markets. These custom checks provide the additional, focused reliability coverage that supports selected market success.

However, the increasing number of reliability checks for different applications, and the increasing complexity of these checks, exposes the need for a verification flow in which designers can select and configure combinations of checks quickly and easily, without having to manage check complexities during the run. Providing a flow that permits designers to easily configure and run custom checks with different check combinations helps design companies achieve today's demanding time-to- market schedules for chip design and validation.

Check combinations

Different IC designs have different reliability aspects and concerns that must be analyzed. Multiple reliability verification needs often require a combination of rule checks, each focused on a specific aspect, to provide full reliability verification coverage. As examples, let's look at two design applications, a design with multiple power domains and an analog circuit design.

Multiple power domains

Designs containing multiple power domains are at higher risk of experiencing electrical overstress (EOS). EOS occurs when an electrical parameter goes past design parameters, and can result in varying degrees of performance degradation, all the way up to catastrophic and permanent failure [9].

Figure 1 shows a device-level EOS condition, in which the pins of a PMOS transistor are connected to different power domains. In this example, if vcc2 is tied to 3.3v, and the gate is switching at 1.8v (vcc1 = 1.8v), this combination creates oxide stress on the m2 gate. This particular layout is a subtle design error that will cause failure over time, as opposed to immediate operational failure.

Complex system-on-chip (SoC) designs, with more analog and digital circuits, require different voltages to support each power domain on the chip. Multiple power

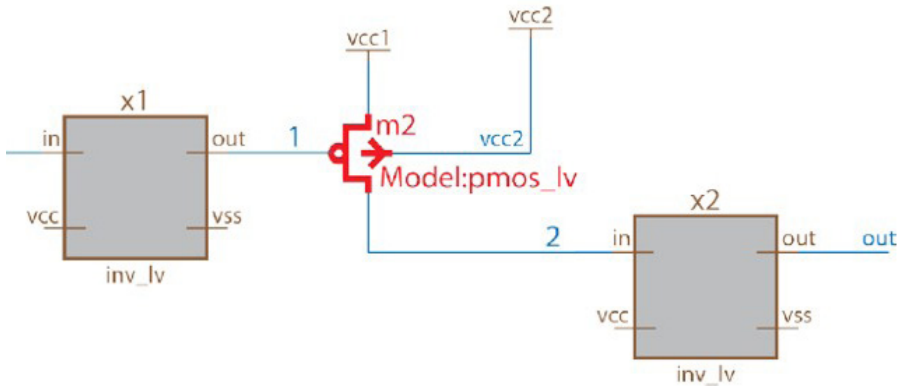

Figure 1. IEC 62506 Methods for Product Accelerated Testing

domains designs have signal nets that must cross from one power domain to another, and these crossing points are often the point of failure or damage. EOS protection schemes are used to control the voltage at these crossing-domains interfaces. Designers

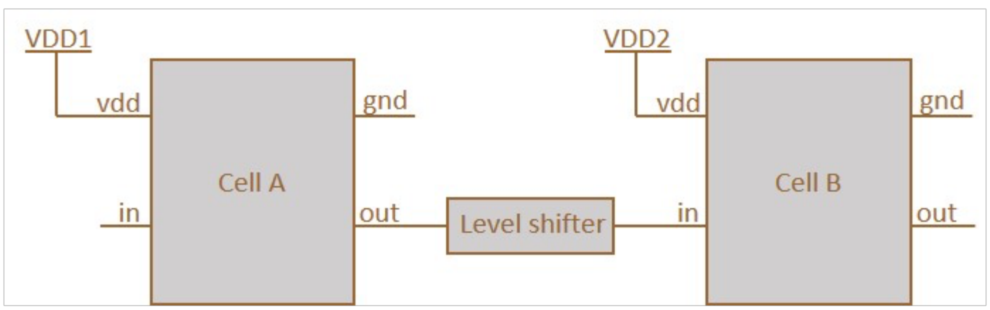

Figure 2: Level shifter circuit connected between signal nets of two different power domains.

insert a level-shifter block to convert from one power/voltage domain to another. If a signal net moves from a low-voltage domain to a high-voltage domain without a low-to-high level shifter, the signal net will not be able to drive the high-voltage domain circuitry to work. If a signal net moves from a high-voltage domain to a low-voltage domain without a high-to-low level shifter, the signal will over-drive the low-voltage domain circuitry, leading to device damage over time.

Consequently, a missing level shifter is a reliability risk. Designers must verify not only that the appropriate level-shifter is in place at each domain interface, but also that it is correctly connected (Figure 2).

Validating these types of designs requires running both an EOS check to detect devices connected to different voltages, and a level-shifter check to detect the existence of level shifters. Without both checks, the reliability verification is incomplete.

Analog Circuitry

Analog circuits are typically very sensitive to changes in layout design technique, operating conditions, and process variation. For common analog circuits, such as a current mirror, the ratio between devices is essential to achieving correct design performance. One of the challenges in analog design is to accurately implement and maintain these ratios in the layout. Analog designs are also highly susceptible to variations in the manufacturing process, which can result in unintended effects in the manufactured circuitry. All of these challenges together can negatively impact analog circuit reliability and robustness in general, which can make it difficult to design circuits that perform reliably over the expected product lifetime. To fully validate analog layout reliability, designers must typically run multiple checks, including layout symmetry, device matching, well proximity effect (WPE), pitch consistency between devices, and others.

For example, layout constraints are used to minimize physical variations for group devices that should behave similarly, such differential pairs or current mirrors [10]. A symmetry check between devices ensures the devices all have symmetrical shapes around either horizontal/vertical axes, or around center (Figure 3). For an array of devices, checking for matching between device shapes and the same pitch between all the devices ensures the uniformity of the array.

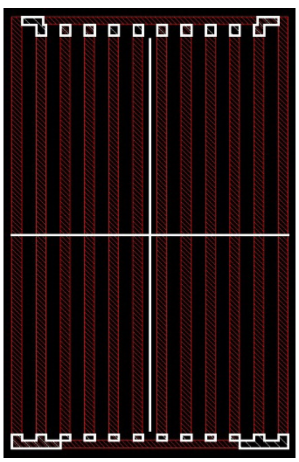

Figure 3. Reliability checking reveals symmetry mismatches around the vertical axis.

WPE is another important reliability impact for analog designs. Well proximity is the distance between devices and the edge of the well in which they are placed. For the devices to age symmetrically, all devices in a well must have the same spacing to the edge of the well. Devices with even a small difference in the distance between the device and the well edge will age differently, which can lead to performance degradation, and eventually a reduced product lifetime [11]. Figure 4 shows a case of WPE, where devices A, B, and C don't have the same spacing distance to the well edge.

Check packaging

With increasing design complexity and a heightened focus on reliability at all levels of chip design, from IP to full-chip, accurate and full verification coverage of the different reliability concerns within an IC design is essential. Both foundry and custom reliability checks may be needed to ensure a design will perform as intended for the life of the product. However, using manual selection and setup to ensure the correct checks are always run for every specific condition is both time-consuming and subject to human error. A faster, more accurate, and more consistent way to ensure proper reliability verification is to make use of a packaged check framework that supports simple selection and configuration of pre-coded checks.

Well-written pre-coded checks contained in an easy-to-use packaged flow enable designers to run the correct combination of checks, without the need for custom check coding at runtime. To ensure designers can cover different reliability aspects when and as needed, it's also important that

Pick a Package of Reliability Checks for Consistent, Accurate Verification

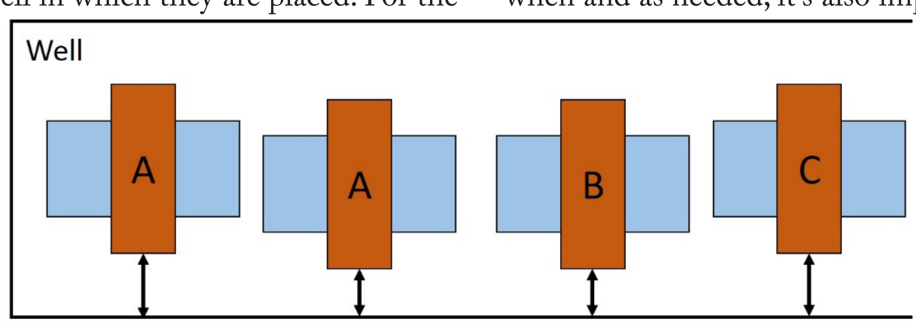

Figure 4: WPE leads to differences in device aging, which contribute to performance degradation over time.

Pick a Package of Reliability Checks for Consistent, Accurate Verification

the flow allows them to combine multiple checks whether they're running verification on the target design, intellectual property (IP) block, or full chip.

With a check package, designers can quickly and easily combine multiple reliability checks into a single reliability verification run, maximizing ease-of-use and minimizing runtime setup (Figure 5). The input for the packaged checks flow is a user configuration file, in which the designer can select checks and configure the parameters of each check based on the needs of the design. This input constraint file is processed by a package manager, which accesses the checks database and creates a rule file containing all of the selected checks, with the proper configuration parameters to run on the designated design [12].

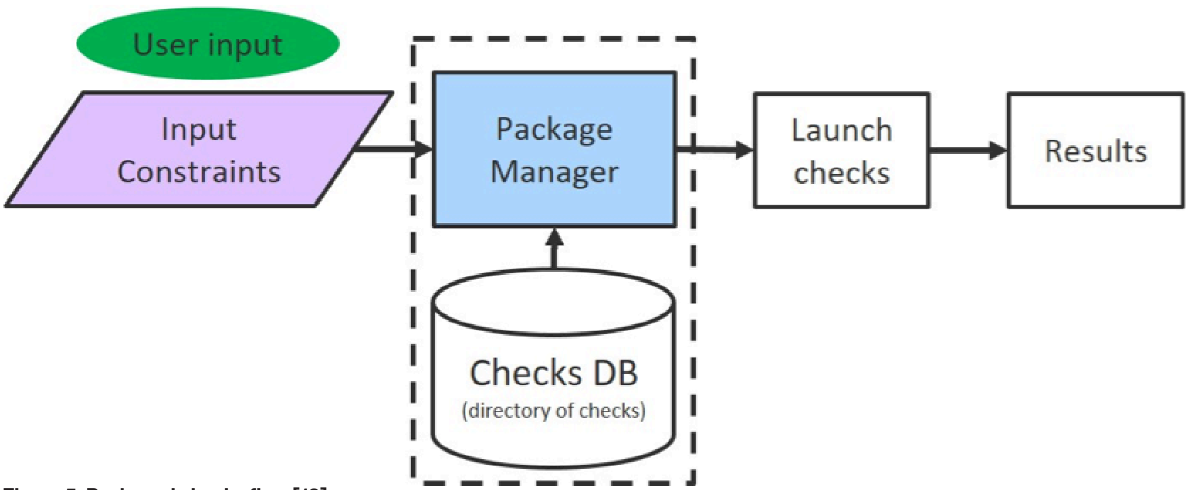

Figure 5. Packaged checks flow [12].

Reliability coverage and the nature of the specific checks available to designs is dependent on the checks contained within the particular checks database being referenced. The referenced library may contain the complete set of reliability checks available, or a subset focused only towards specific design requirements. Examples of checks that might be contained within a particular check library include the following:

- Device count (all and specific types)
- Electrical overstress
- Level shifter detection
- Find patterns in the design
- Crosstalk susceptibility
- Hot carrier injection (HCI)
- Topology-aware latch-up
- Voltage-aware latch-up
- Voltage-aware design rule checking (DRC)
- IO ring checking
- Static supply analysis and identification
- Hot junction identification
- WPE susceptibility (device aging)
- Differential pair symmetry
- Analog constraints checks
  - symmetry, device matching, common centroid of devices, pitch checking, parameter match, cluster, device alignment, dummy device presence

As with other rule decks, results are generated and reported per check. While packaged checks make it easier to select and combine checks, running multiple checks in combination can also change how results are displayed. Figure 6 shows the results of EOS, level shifter, and device count checks using a packaged checks flow, where EOS and level shifter checks report error results, and a device count check reports informational results. The designer can debug these results (both error and informational) using a results viewer.

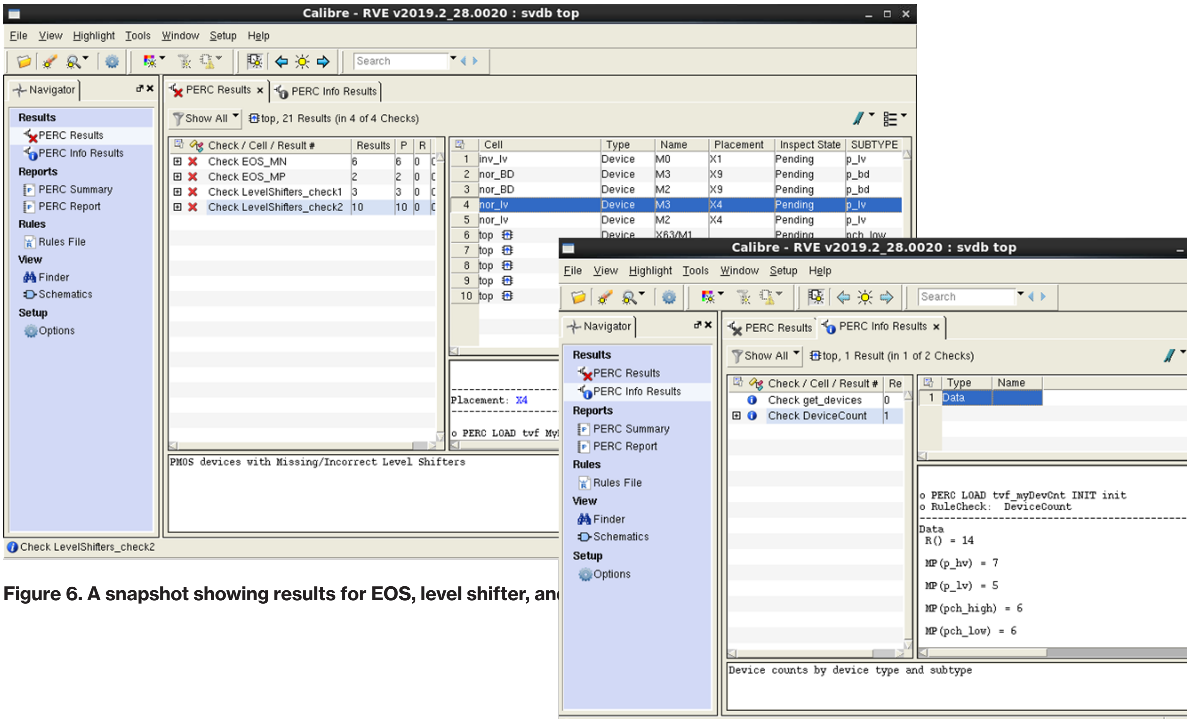

Figure 6. A snapshot showing results for EOS, level shifter, an

Conclusion

Today's complex reliability requirements may require multiple checks to ensure complete and accurate reliability verification. Rather than relying on checklists and manual selection, employing a package checks flow can help design companies ensure that the right mix of checks are run consistently at all levels of design verification. A packaged checks flow enables designers to quickly and easily select, configure, and combine multiple pre-coded checks, either by themselves or with the guidance of their central CAD or reliability team. With minimum setup, a packaged checks flow enables designers to select and combine checks without having to worry about coding any complex setup or runtime conditions. As a result, running reliability verification is easier, faster, and more consistent, which helps shorten the design time cycle while safeguarding product reliability.

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Time to Choose between Scientific and Administrative Approach

Jezdimir Knezevic

"If you watch a glacier from a distance, and see the big rocks falling into the sea, and the way the ice moves, and so forth, it is not really essential to remember that it is made out of little hexagonal ice crystals. Yet if understood well enough the motion of the glacier is in fact a consequence of the character of the hexagonal ice crystals. But it takes quite a while to understand all the behaviour of the glacier (in fact nobody knows enough about ice yet, no matter how much they've studied crystal). However, the hope is that if we do understand the ice crystal we shall ultimately understand the glacier."

R. Feynman, "The Character of Physical Law"

Reliability Theory, since its beginning in 1950's, has been based on mathematical theorem rather than on scientific theories. Massive attempts were made to further applications of the existing mathematical and statistical methods and analysis without attempts for understanding "failure mechanics." Then, in 1980s, practicing reliability engineers and analysts, who have neither ability to understand the mathematics, turned to what they have had, which is enormous practical experience of the observed failure modes of existing systems. Thus, a large number of "practical reliability methods" have been developed and used, all of which were based on the Failure Mode, Effect and Criticality Analysis, FMECA, but still without any attempt to understand and address physical mechanisms that generate failures. Consequently, during the last 50 years the Reliability Theory made very little progress, apart from a few exceptions, in the direction of becoming the science, in terms of making accurate predictions that could be confirmed with practical observations. The reason is very simple; neither statistics, which does not study causes of statistical behaviour, nor engineers whose "applied methods" were focused on meeting contractual and legal requirements, by doing FMECA to "prove" Mean Time Between Failures (MTBF) were able to provide a fertile ground for the development of reliability.

To illustrate the above statement the fundamental expression for reliability will be used. It is generally accepted that reliability is the probability that a system will operate without failure during a stated period of time, which is mathematically represented by the following expression:

$$R(t) = P(TTF > t) \qquad (1)$$

where: TTF is a random variable known as the Time To Failure and R(t) is the reliability function.

However, today there are two distinguished approaches to calculation of the probability defined by the above equation. They are:

Approach 1, where calculation of the probability of a successful operation with internal of time from 0 to t is based on the following expression:

$$P(TTF > t) = \prod_{i=1}^{nfm} P(TTF_i > t) \qquad (2)$$

where *nfm* is a total number of competing failure mechanisms that can generate a failure event. It is necessary to stress that a probability distributions that define individual failure mechanisms are exclusively determined by the physical processes that generate them, like fracture, single event upset, electrostatic discharge, fatigue, creep, wear, radiation, hot electron, embrittlement, depolymerisation, charge trapping in oxides, glass transition and many others.

Approach 2, well established within western defence aerospace, oil and other industries, for all reliability predictions, risk and safety assessments, conformances, contracting and similar activities, where the probability of operation without failure during a given interval of time t is defined by the following expression (3):

$$P(TTF > t) = e^{\left[-\left(\sum_{i=1}^{nfm} \lambda_i\right) t\right]} = e^{\left[-\left(\frac{t}{MTBF}\right)\right]} \quad \text{where} \quad MTBF = \frac{1}{\sum_{i=1}^{nfm} \lambda_i}$$

where: λ_i is the failure rate of each failure mechanisms that can generate a failure even.

Both expressions for reliability function clearly demonstrate that the system reliability follows the laws of probability. However, the expression 2 allows the probability laws to be driven by physical processes and mechanisms that take place in the system or result from the interaction of a system with natural and human environment, whereas the expression 3 has one, and only one, predetermined future, irrespective of physical properties of systems, their operational conditions, maintenance policies and support strategies. In fact the second approach completely ignores existence of corrosion, fatigue, creep and many others, scientifically observed and well understood mechanisms, which have time-dependent failure mechanisms. To make the distinction between these two approaches to reliability the former will be called the scientific approach and the latter the administrative approach.

Consequently, the main objective of this paper is to argue that the scientific approach to reliability is the only way forward for all members of the reliability community who wish to make accurate predictions that will be confirmed during the operational processes of the future systems. Only then, accurate and meaningful reliability predictions become possible, which is imperative for the development of Risk-Based Technology and its successful applications.

Scientific Approach to Reliability

Mathematically, reliability is defined as a probability that a system will maintain a required function during a stated period of time (see equations 1, 2 and 3). However, as a probability cannot be seen or measured directly, engineers and managers, have fundamental difficulty in understanding and interpreting statistical and probability functions associated with their systems. This is because physical characteristics of a system like the weight, temperature, volume and similar have a clear and measurable meaning. However, the concepts of probability, and hence reliability, is an abstract property of a system that obtains a physical meaning only when behaviour of a large sample of systems is considered. Hence, understanding of reliability is reduced to the scientific observation and analysis of system failures, which are observable and measurable physical phenomena.

According to the Mirce Mechanics, system failures are events that cause transition of a system from positive to negative functionability state [1] due to some of the following reasons, or combinations of them:

- Built-in design errors (incorrect selection of materials, stresses shapes, etc)
- Production problems (human errors, material and process deficiencies)
- Irreversible changes in the condition of components with time due to wear, fatigue, creep, corrosion, and similar degradation processes
- Imposition of external overstress mechanisms resulting from collisions, harsh landings, extreme weather conditions, etc
- Human errors in execution of maintenance tasks
- Human errors in execution of in-service support tasks

At the MIRCE Akademy a large number of failure events and associated phenomena have been observed and analysed to understand the physical mechanisms that generate occurrences of failures.

Consequently, systematic studies are applied to understand phenomena that cause thermal aging, thermal buckling, photo-chemical degradation, reduction in dielectric strength, evaporation, metal fatigue, actinic degradation, photo-oxidation, swelling/ shrinking, degradation of optical qualities, fogging, photochemical decomposition of paint, blistering, warping, thermal stress, breakdown of lubrication film, increased structural loads, shift in the centre of gravity, jammed control surfaces, attenuation of energy, clutter echoes, blocking of air intakes, decreased lift and increased drag, unequal loading, removal of coating protection, pitting, roughening of the surface, acid reactions, leakage currents, promotion of mould growth, reduction of heat transfer, caking and drying, premature cracking, hot spots creation, erosion, bleaching preservatives, abrasive wear, corrosion, alkaline reactions and similar.

For years, research studies, international conferences, summer schools and other events have been organised in order to understand just a physical scale at which failure phenomena should be studied and understood. In order to understand the motion of failure events it is necessary to understand the physical mechanisms that cause the motion. That represented a real challenge, as the answers to the question "what are physical and chemical processes that lead to the occurrence of failure events" have to be provided. Without accurate answers to those questions the prediction of their future occurrences is not possible, and without ability to predict the future, the use of the word science becomes inappropriate.

After numerous discussions, studies and trials, it has been concluded that any serious studies in this direction, from Mirce Mechanics point of view, have to be based between the following two boundaries:

- the "bottom end" of the physical world, which is at the level of the atoms and molecules that exists in the region of 10^{-10} of a metre [3],
- the "top end" of the physical world, which is at the level of the solar system that stretches in the physical scale around 10^{+10} of a metre. [4]

This range is the minimum sufficient "physical scale" which enables scientific understanding of relationships between system operational processes and system operational events. In other words, this is the physical range within which, the system operational processes mentioned above (fatigue, the wind direction change, suncups formation on the blue ice runway, bird strike, perished rubber, carburettor icing) take place and as such they could be understood and predicted.

The Bottom End: Atomic System

All matter in the Universe is made of elementary building blocks called atoms. Complex interactions between atoms govern existence of larger building blocks. [2] For example two or more atoms form molecules, ranging from simple oxygen molecules to large polymers and other macromolecules. Besides this way of building the matter, atoms can arrange in periodic structures called crystals. Examples of crystals are numerous, from the rock salt (crystal of Na and Cl), over diamond (made of C atoms) and crystal of Iron to recently synthesized crystals in the field of Nanotechnology, to mention just nanotubes and graphene – the miracle materials with large promise for the future applications. While the average size of atoms is 10^{-10} m crystals can grow to macroscopic dimensions of the order of a meter, making objects like airplane wings, car bodies etc. The very atomistic nature of these objects governs their mechanical, electronic, thermal and other physical properties, which are of interest for Mirce Mechanics. Additionally material defects, fatigue and other features, which can in the final instance, lead to the failure of material and finally a cancellation of flight or even a disaster, are originated at the atomic level. Quantum mechanics, a physical theory developed in 1920s, in exact way describes the matter at the atomic scale. This theory has the power to predict the evolution of material under stress, corrosion or other environmental influences, which complements Mirce Mechanics, giving meaningful values to the missing parameters of the theory.

The Top End: Solar System

The Solar System may seem enormous, looking from the human perspective, but it is only a very small corner of the Universe. However, the entire solar system contains only eight planets that move in elliptic paths around the Sun. All of them are lit by the Sun and do not produce their own light. The distance between the Earth and the Sun is 150 million kilometres; hence the number for the top end of 10^{10}. Thanks to its thermonuclear reactions which last for 5 billion years, the Sun irradiates enormous energy each second in the form of electromagnetic and other radiations, out of which only ~$1/10^9$ fraction reach the Earth. Owing to them rivers flow, winds blow, forests rustle and the human race flourishes.) About a half of that energy (0.8×10^{17} watts) reaches the terrestrial surface, which is 5×10^{14} square metres, making the average power of the solar radiation at ground level is 160 watts/m^2. The 99.9 % of it is absorbed by the soil, and goes into the evaporation of water, causing winds, thunderstorms, and all that we loosely call weather. Thus, only 0.1 per cent of the radiant energy of the Sun (around 10^{14} watts) is captured by plants through photosynthesis of organic substances from carbon dioxide and water. This energy supports all the living things on Earth, from bacteria to animals and humans.

From system reliability point of view, the solar system is significant in the respect to the "making" of the weather, which is the day-to-day condition of the atmosphere. It is one of the main drivers of system reliability, as it is "responsible" for the

- temperature and pressure of the air,
- wind speeds and directions,
- moisture in the air, precipitated as rain, snow, hail, sleet, dew or frost.

All air contains moisture in the form of water vapour, which is water in gaseous form. As warm air can hold more water vapour than cold air, when it is cooled its capacity to hold water vapour decreases, and finally the air is completely saturated, having a relative humidity of 100 per cent, known as *dew point.* Further cooling beyond dew point leads to water vapour condensing around nuclei, such as specks of dust or salt, to form water droplets or, in cold air, minute ice crystals. Large quantities of condensed water vapour form clouds, by which water is continually conveyed from the oceans to the land, where it is released from the air as precipitation. This provides the land with the fresh water needed by animal and plant life. Finally, the water completes the cycle by returning to the oceans.

An Example: Impact of Cosmic Rays on Avionics Reliability

In order to illustrate the necessity for the physical scale of studies of reliability phenomena proposed in this paper to be from 10^{-10} to 10^{+10} of a metre, the impact of cosmic rays on reliability of avionics will be presented here. It has been concern for avionics, since the late 1980's when the primary radiation phenomenon, which had previously been observed in orbiting satellites only, also began to appear in aircraft electronic systems. The interaction of this radiation with avionics can result in occurrence of Single Event Effect, SEE, which can be manifested as a transient 'soft error' effect such as a bit flip in memory or a voltage transient in logic. Alternatively, a 'hard error' can be induced resulting in permanent damage such as the burn out of a transistor. Due to the rapid advances in electronics technology and the unrelenting demand for increased avionics functionality in the competitive commercial aircraft industry, the complexity of avionics systems has risen exponentially. If device memory cells used for flight safety or mission critical functions are affected the concern is that the loss of key system functionality due to corrupted data could cause a flight safety or mission critical failure. Baumann in [3] stated that: "Left unchallenged, SEEs have the potential for inducing the highest failure rate of all other reliability mechanisms combined."

Advanced microprocessor and memory semiconductor devices used in modern avionics exhibit an increased susceptibility to SEEs caused by ionising radiation from the following two main sources:

- Cosmic rays from space (10^{+10} of a metre and beyond) that are individual energetic particles that originate from a variety of energetic sources ranging from our Sun to supernovas and other phenomena in distant galaxies all the way out to the edge of the visible universe. Although the term cosmic ray is commonly used, this term is misleading because no cohesive ray actually exists. The majority of cosmic rays consist of the nuclei of atoms (atoms stripped of their outer electrons) ranging from the lightest to the heaviest chemical elements. In terms of composition about 90% of the nuclei are hydrogen, therefore just single protons, 9% are helium, alpha particles with the remaining 1% a mix of heavier element nuclei, high energy electrons, positrons and other sub-atomic particles. Within the atmosphere the three most important parameters used to define the variability of the particle flux at a specific location are: altitude, latitude and energy. Within the field of cosmic ray physics altitude is expressed in terms of atmospheric depth, which is the mass thickness per unit of area in the Earth's atmosphere. Cosmic rays can be broadly divided into two main categories, primary cosmic rays and secondary cosmic rays. Primary cosmic rays are particles accelerated at astrophysical sources and generally do not penetrate the Earth's atmosphere. Secondary cosmic rays are created when primary cosmic rays collide with oxygen and nitrogen nuclei in the atmosphere and break into lighter nuclei in a process known as cosmic ray spallation.

- Alpha particles from radioactive impurities in the materials of which device are made (10^{-10} of a metre and below). They are doubly ionised helium atoms consisting of two neutrons and two protons that can also be described as a helium atom that has been stripped of its electrons. When an alpha particle travels through a material it will lose kinetic energy primarily through interactions with the materials electrons, leaving a trail of atoms with "kicked out" orbital valence electrons. This process is called ionisation and it can be described as the physical mechanism that converts an atom or molecule, into a positively or negatively charged state by either adding or removing charged particles. The resulting atom is then referred to as an ion, or more specifically a cation if positively charged or an anion if negatively charged. The issue of alpha particle generating source contaminates first arose in the late 1970s when Intel discovered high soft error rates in new DRAMs when the integration density increased from 16K to 64K. The problem was traced to a semi-conductor packaging plant that had just been built downstream from an abandoned uranium mine. The ceramic packages were being contaminated by radioactive contaminants in the water. Low energy alpha particles are emitted from the decay of trace radioactive materials in semi-conductor device and packing materials.

The relationship between the radiation particles and the failure mechanisms of the single events upsets is shown in the Table below. [4]

As the reliance on avionics systems within aircraft increases so do concerns regarding the reliability of these systems, particularly for those systems, which are considered safety critical. Hence, to take the appropriate mitigating actions and enable decisions to be made at the design stage a method needs to be devised that will facilitate the calculation of soft errors rates due not only to quiescent conditions, but also to take into account more exceptional solar influenced events.

The research currently undertaken within the MIRCE Akademy has two main objectives;

- the development of an SEE functionability prediction model
- the use of the model to investigate the influence of space weather, flight route and a multitude of other aircraft and system design factors on the resultant shape of the distribution of SEE initiated failure events through time.

The main areas of research are: the investigation on the influence of the aircraft structure on the internal neutron flux spectra at specific inside locations of the architectures of future commercial aircraft and the evaluation of the methods and techniques used by the electronics industry today to assess their suitability for the inclusion into the SEE functionability prediction model.

A plethora of device and circuit level simulation methods exist together with a range of empirical techniques exist that could be used at various indentures levels. The integration of these methods into an SEE functionability model may lead to an improved understanding of SEE fault propagation mechanisms resulting in a more accurate prediction of failure events at system level. The final goal is the creation of an innovative SEE functionability prediction model that will enable the future behaviour of an avionics system to be predicted for a whole host of different external parameters such as the extremes of space weather or different flight routes.

Furthermore the model should allow system designers the flexibility to examine the full range of system design options such as device selection, system configuration and SEE reduction solutions to allow early functionability improving design decisions to be made, with least investment in time and resources.

Conclusion and Recommendation

The main objective of this paper was to present the authors approach to Reliability, one that is based on the laws of science. I do not believe in the existence of parallel universes where the laws are either ignored or bent to accommodate administrative or contractual requirements. A prime example of the latter is the well accepted model of system reliability that requires the acceptance of "alternative universes" to support the argument that the components and consequently systems possess a constant, time independent, failure rate, as described by the equation 2. This approach stems from neither science nor observation, but from imaginary steps envisaged in the minds of its proponents who allowed all laws of science to be suspended. However, this view is in direct opposition to the observed functionability phenomena like corrosion, fatigue, creep, wear, quality problems and many other time dependent physical processes that clearly demonstrated

Radiation Type	Radiation Source	Method of Charge Deposition	Failure Mechanism
Thermal neutrons	Secondary cosmic ray neutrons	Indirect Ionisation	Interaction between thermal neutrons and materials containing the Boron-10 isotope creates secondary ionising particles.
Low energy alpha particles	Radioactive decay of uranium and thorium impurities located within the device materials.	Direct Ionisation	4 to 9 MeV alpha particle, creating an electron hole funnel.

Table 1: Summary of Failure Mechanisms

that the components/system reliability for a stated period of time could have increasing, constant and decreasing probability of success in respect to the stage of the life of a system, consisting components and maintenance policies applied, as the science based approach caters for through the reliability function defined by the equation 1.

Finally, it is essential to distinguish the scientific approach to the formulation and modelling of the motion of reliability through the life of a system, contained in Mirce Mechanics and presented in this paper, from administrative approach that is based on reliability models of systems that are created to demonstrate the contractual compliance of the legally binding acquisition processes, in western defence and aerospace industries.

As science is the proved model of reality that is confirmed through observation, the summary recommendation of this paper to reliability professionals is to move from the universe in which the laws of science are suspended to the universe that is based on the laws of science in order for their predictions to become future realities.

It is encouraging to know that Rolls Royce reliability department in Darby, England, routinely recognises over 50 different failure mechanisms in reliability modelling of their jet engines.

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Appendix 1: Mirce Mechanics Concept

Mirce Mechanics - scientific study of the motion of functionability through the life of a human made and managed system to:

- Experimentally determine the pattern of the motion
- Scientifically understand mechanisms of the motion
- Mathematically defined laws of the motion
- Predict the pattern of the motion of a given system

Functionability, the ability of being functional, is the fundamental property of in-service performance of any system. It is an emergence property of a system, in time domain, resulting from the complex interactions of natural phenomena, such as fatigue, corrosion, creep, wear, humidity, wind, hail, foreign object damage, solar radiation and similar, on one hand and from human actions taken in respect to the type, content and timing of operational, maintenance and support processes, on the other.

To achieve the above objectives Mirce Mechanics concept, principles and methods have evolved from the experimental, theoretical, computational and applied aspects of research, each of which is briefly described below.

Experimental Mirce Mechanics focuses on the determination of the pattern of the motion of functionability through the life of a system resulting from the occurrence of functionability events. Existing experimental and observed data clearly demonstrate that the motion of functionability through life of a large number of "identical" systems deliver a large number of different functionability patterns, while delivering "identical" functionality. Consequently, it is statistical experiment that requires the use of statistical methods to calculate the average pattern and associated measures. However, as statistics does not study the causes of statistical behaviour it is the task of Mirce Mechanics to scientifically understand the mechanisms that cause the motion of functionability in time. Thus, functionability phenomena that cause occurrence of positive and negative functionability events are subjected to the analyses within physical scale between 10^{-10} metre (for the understanding atomic and molecular phenomena) and 10^{+10} metre (for the understanding of cosmic and environmental phenomena).

Theoretical Mirce Mechanics focuses on the mathematical definition of the patterns of the motion of functionability through the life of a system. Mathematically formulated law of the motion, in respect through time, which accurately represents the observed patterns, is defined by the expression, named Mirce Functionability Equation, which has been developed by Dr J. Knezevic at the MIRCE Akademy. It defines, in the probabilistic terms, the expected patterns of functionability trajectory and associated measures for a given system, operational rules and conditions. Although the laws of probability are just as rigorous as other mathematical laws they are not able to predict the motion of functionability through the life of each individual system, they can only predict the probability of each individual system being in a given functionability state at a given instant of time.

Computational Mirce Mechanics focuses on the quantitative evaluation of Mirce Functionability Equation for a given system and given in-service rules and conditions, as the analytical solutions to these equations are too complex to be solved mathematically. Consequently, it is the task of Mirce Mechanics to develop effective computational methods that will enable construction of models that accurately represent the observed reality of system behaviour, rather than to simplify system reality to cope with mathematical limitations. The Monte Carlo method has proved very successful in Quantum Mechanics for finding practical solutions to multi-dimensional integral equations that are of similar nature to those of the Mirce Mechanics.

Book Review: Reliability Prediction and Testing Textbook

Lev M. Klyatis, Edward L. Anderson
Reviewer: Russell A. Vacante, Ph.D.

During the early pages of this textbook the two authors Lev Klyatis and Edward Anderson, state, "without accurate simulation of real-world conditions, test results may be very different from the real world." From my perspective this is the cornerstone theme for all reliability modeling and prediction methodologies discussed by the authors. Their focus on this theme causes me to reflect on my early career attempts to gather "real-world" failure data from the field. Capturing this data was only partially successful given the limited human resources available to do so and the spotty communication network existing at the time. Back to the book!

What the authors are saying is that "accurate physical simulation of "field data" is a necessary first step towards achieving reliability modeling and predictions. To back this observation up, the authors provide a brief historical and acute technical insight into the various past and present reliability models, mythologies and testing procedures. For example, they address the background and use of MIL-HDB 217, the Bellcore/Telcordia Predictive Method, Physics of Failure (for electronic components) approach, and Life Testing Methodology. The authors underscore how they have been used, their attributes, and most importantly why they, for the most part, have only met with limited success in their application for predicting product performance.

The graphic on page 30 of the textbook nicely demonstrates that "reliability" is only one of many factors that helps determine a product's technical performance in the field. Factors such as safety, durability, and life cycle cost, among others, play an important role. While reliability may be only one of the factors that help to determine a product's technical performance the above-mentioned other factors do impact the overall reliability of a product. The trade-offs that are made pertaining to safety, maintenance and cost when developing a life cycle strategy have been known to both enhance and deteriorate product reliability. From a systems engineering perspective, they are all interrelated. The design and development teams may find it in their interest to reduce the robustness of a product's inherit reliability by having the end user organization maintain product availability through the use of spares.

The use of accelerated reliability/durability testing, ART & ADT respectfully, comes close to reflecting a product operating environment when periodic field data and laboratory simulation is combined. In this manner the field input has direct input on the variables such as output, vibration, tension, loading etc. On page 83 of the textbook the authors provide an excellent example of numerous inputs that should be considered to perform reliability predictions. This chart is a handy reference designed to make us mindful of real-world influences that will help lead to more accurate reliability predictions.

In summation, this book deserves high marks in providing an overview of the reliability methodologies and tools used in the past and at present. This book is a must read for engineers and managers who are interested in improving their engineering culture. The most important take-away for me is that this book, from cover to cover, holds true to its opening theme: "without accurate simulation of real-world conditions, test results may be very different from the real world." The absence of real world data in the previous reliability modeling and prediction methods is a flaw from which they cannot escape. Recent computer and related technologies have made the task of acquiring "real-world" data much easier and timelier. No testing is complete without it. As the authors have succinctly stated, without it the number of vehicles recalled, due to poor reliability-performance will continue to grow. Engineers - take the observation of the authors seriously. Make certain that you incorporate real-world data when doing accelerated reliability/durability testing.

Colophon

The Journal of Reliability, Maintainability, & Supportability in Systems Engineering

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The Journal of Reliability, Maintainability, and Supportability in Systems Engineering

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Pick a perfect package of reliability checks for consistent, accurate verification

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Time to Choose between Scientific and Administrative approach to Reliability

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Book Review: Reliability Prediction and Testing Textbook

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