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Past, present and future of reliability approaches

Willem van Driel

29 NOVEMBER 2018
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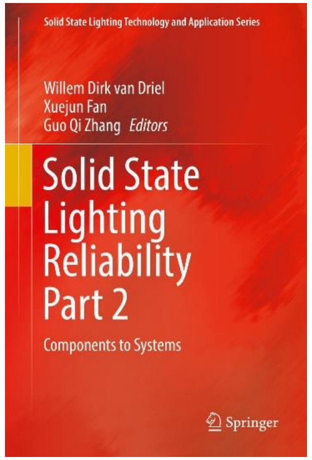
TOMORROW'S RELIABILITY

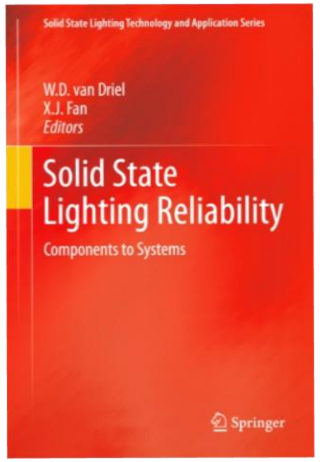
Short Intro

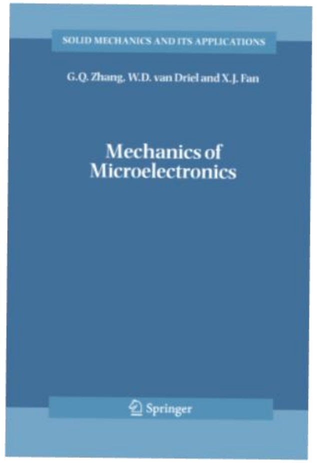
- >25 years experience in reliability
- Radboud; TNO; SHELL; NXP

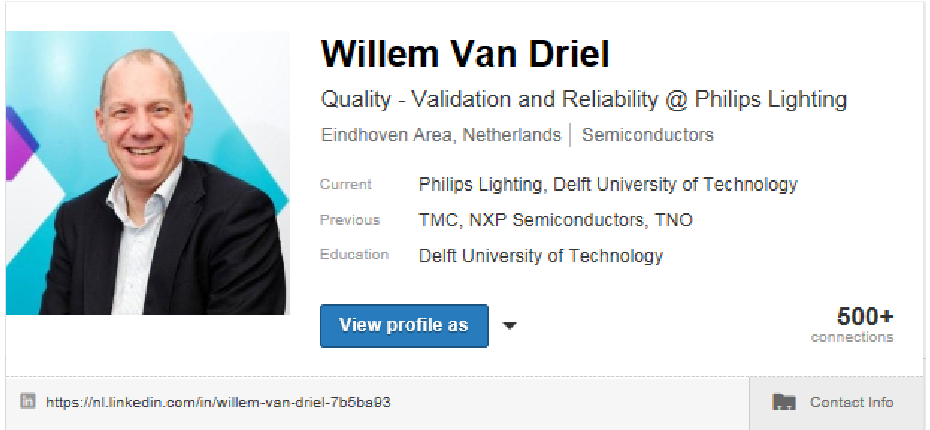
Current positions:

- Master Reliability @ Signify (formerly Philips Lighting)
- Part-time Professor Delft University of Technology
  - Micro/Nanoelectronics Reliability









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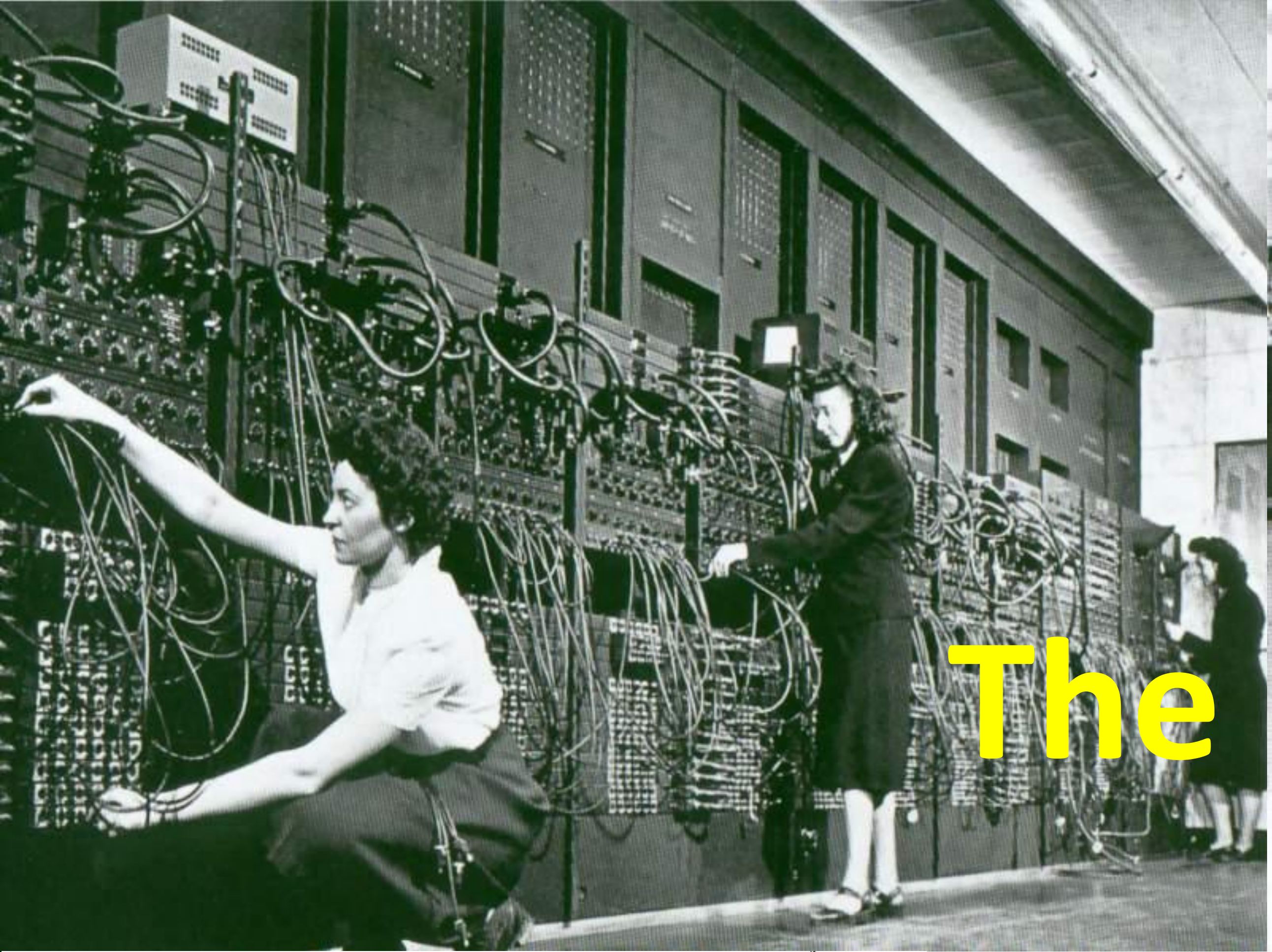
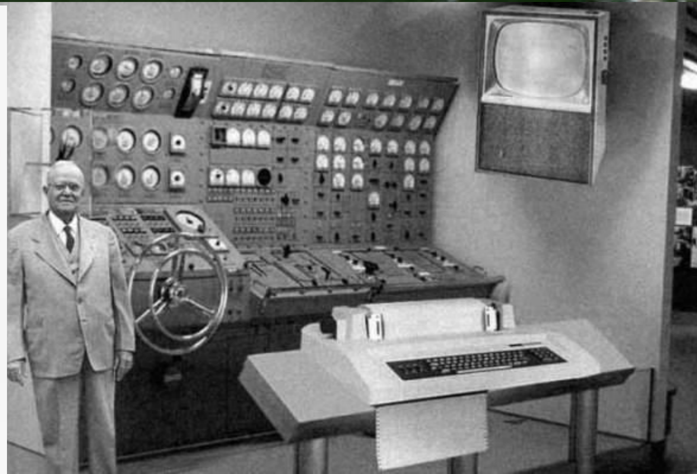
The Past





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Reference Material

1. *Courtesy to Graig Hillman for providing the material of his keynote at EuroSimE2017: ‘Reliability Calculations in Semiconductors - A Short History of Accomplishments.*

2. *Denson W. The history of reliability prediction. IEEE Trans Reliab 1998;47 (3-SP): 321– 328.*

3. *James McLinn, A short history of reliability, The Journal of Reliability Information, January 2011, pp 8 – 15.*

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The past was driven by industries started using semiconductors

- Military, Automotive and Telecom industry
- In the period 1950-1980, component failure rates dropped by a factor of 10

<u>Military</u>
- Use of electronics is key
- Driven by safety
- Standardize approaches
- Issues with vacuum tubes

<u>Automotive</u>
- Automation is key
- Driven by Testing
- 3x77 sample size (0ppm)
- Issues with systems

<u>Telecom</u>
- Communication is key
- Driven by cost
- User experience
- Issues with switches

Military took the lead

And left us with a bunch of standards

That are still being used (unfortunately)

Standard for reliability predictions

1951
US Secretary of Defense

1951
RADC*

1952
AGREE**

1960
Need for forum on "Physical Processes"

1962
Physics of Failure Conference

1968 – 2017
IRPS

1962 – 1991
MIL-HDBK-217

1957
AGREE recommends MTBF

1959
RCA publishes 1st empirical handbook (TR1100)

*Rome Air Development Center
**Ad-Hoc Group on Reliability of Electronic Equipment

The box of reliability prediction opens

MIL-HDBK-217 provided standardized failure rates

- Intent was reliability evaluation at procurement
- Initial versions warned users ‘not to use calculations for reliability predictions’

Philosophy of MIL-HDBK-217

- Failure modes and mechanisms are irrelevant
- Failure rate is constant and modified by adjustment factors (lambda)

Numorous derivates excist: SR-332, Siemens, IEC, FIDES, etc.

Introduction of physics-of-failure principles

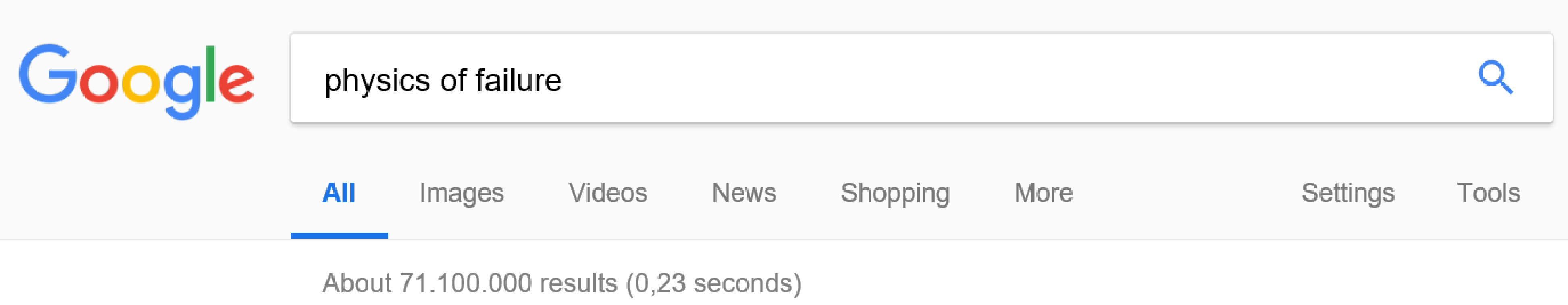
Also known as Reliability Physics

Definition:

> *The process of using modeling and simulation based on the fundamentals of physical science (physics, chemistry, material science, mechanics, etc.) to predict reliability and prevent failures*

Two examples:

- Electromigration
- Solder joint fatigue



Suggestions for reading

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Example: Electro-migration

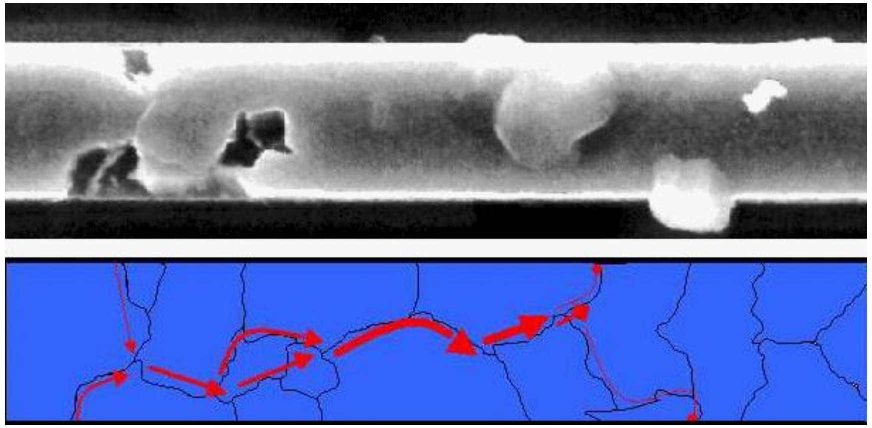
Developed by James Black (1967, Motorola)

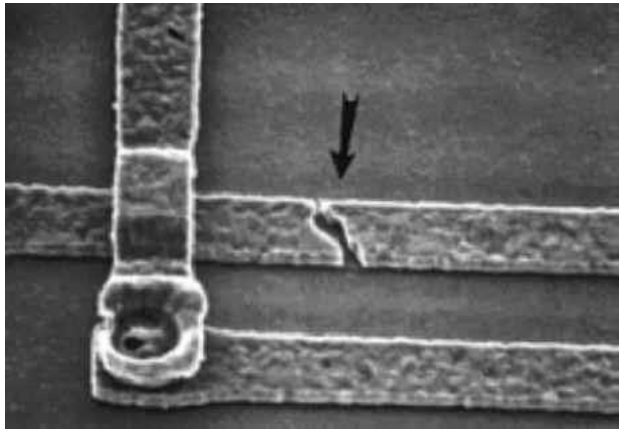
- The displacement of atoms within a conductor caused by flow of electrons and holes
- Creates either voids (electrical open) or extrusions/ hillocks (electrical short)
- Time to failure is inversely proportional to rate of mass transport

Still semi-empirical

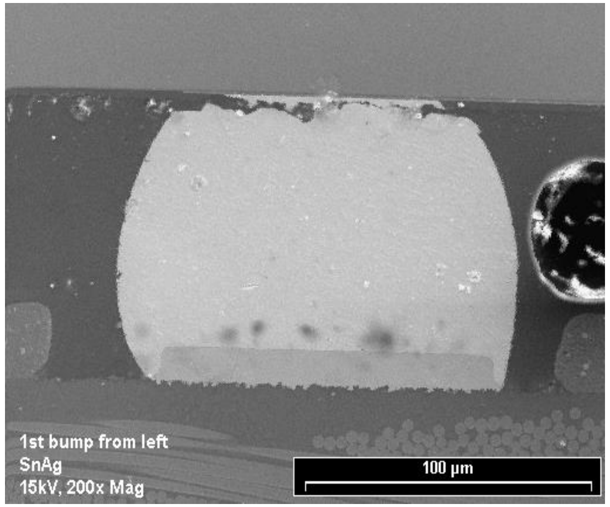
$$t_f = A(J^{-n})exp\left(\frac{E_a}{kT}\right)$$

n: 1-2
Ea: 0.4-1.0eV





Example: Solder joint reliability



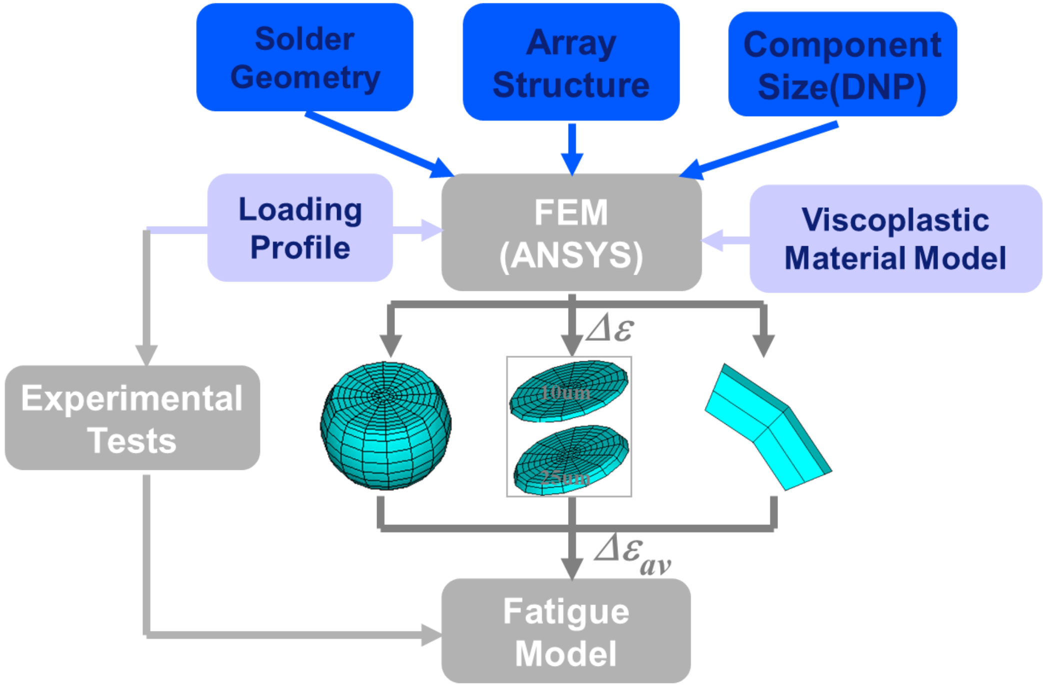
FEM got introduced in solid mechanics (Zienkiewicz, 60-70s)

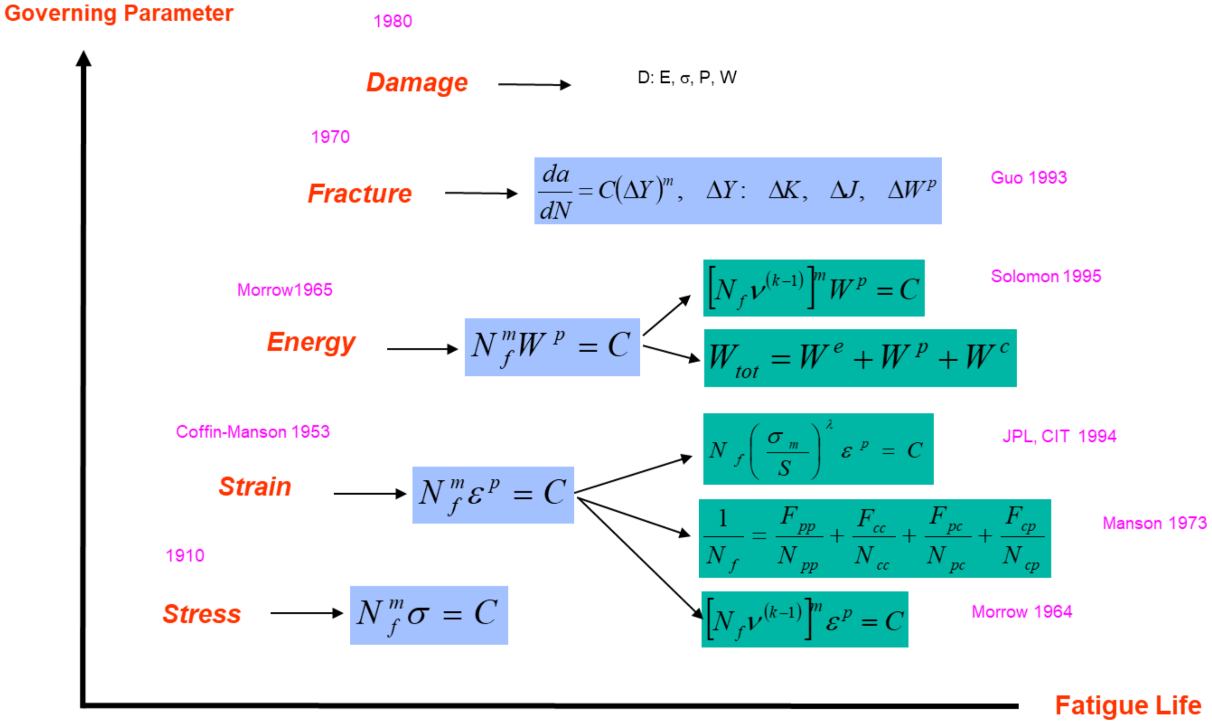
Strong need for material behavior

Lots of phenomenological-based descriptions

Coffin-Manson; Norris-Landzberg, Engelmaier, Darveaux

Standard approach per today is combining these with FEM





Where were you on January 28, 1986?

The Challenger disaster had a clear reliability nature!

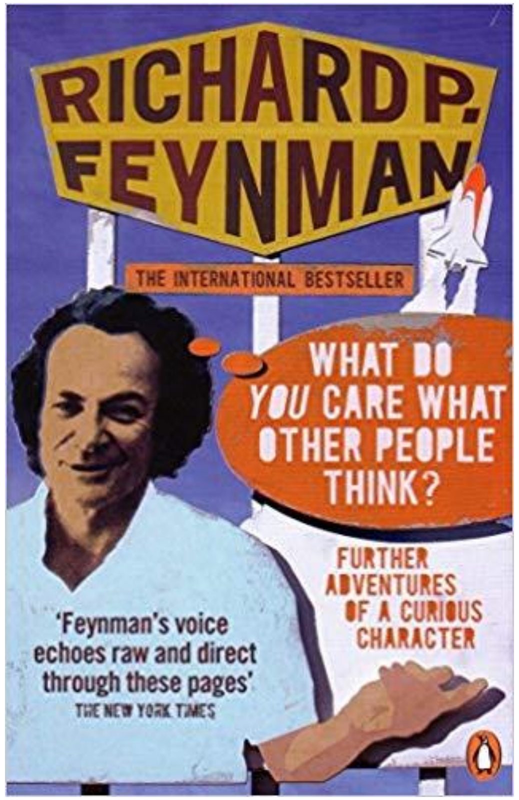
Feynman found the root cause: o-ring failures

Read about Feynman's struggle between managers and technicians:

[Personal observations on the reliability of the Shuttle by R. P. Feynman]

Or buy the book, 10Euro, a must ready for all reliability engineers!

This disaster caused industry to re-evaluate how to estimate risks.



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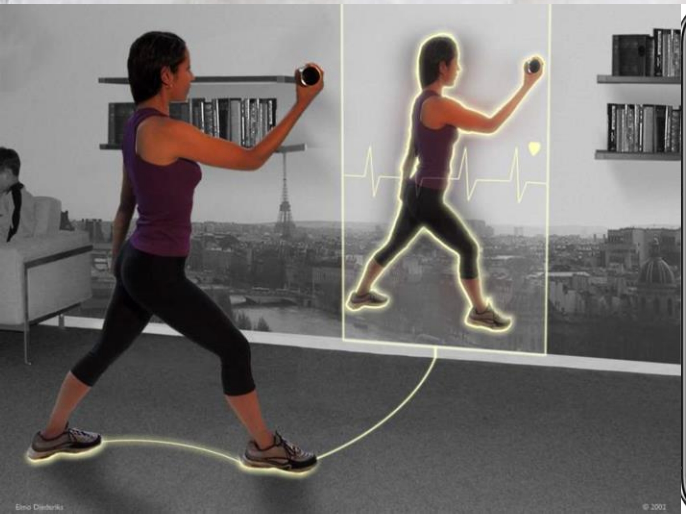
The Present



Reliability: The major concern of high-tech industries

- Direct finance lose: 10 – 15% of global annual industrial revenue; delayed product release; liability; reduced consumer confidence
- Each industry with it’s own key reliability focus areas

<u>Automotive</u>
- Harsh environments
- Electronics & sensors
- <0.5 PPM failure rate
- Data analytics

<u>Aeronautics</u>
- Maintenance & safety
- Sensors & connectivity
- Thermal drift @ batteries
- Data analytics

<u>Lighting</u>
- Long lifetime coverage
- System reliability
- Multi-physic interaction
- Data analytics

<u>Consumer electronics</u>
- Failure not found
- Cost down & TTM
- IOT
- Data analytics

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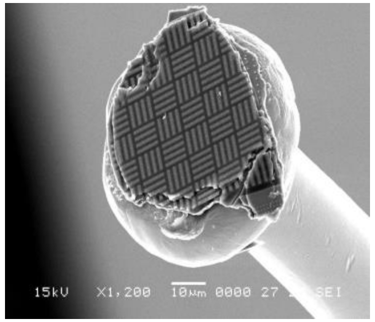
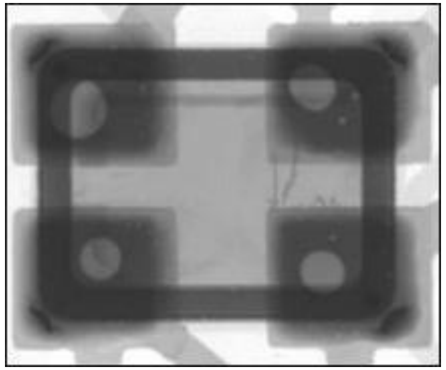
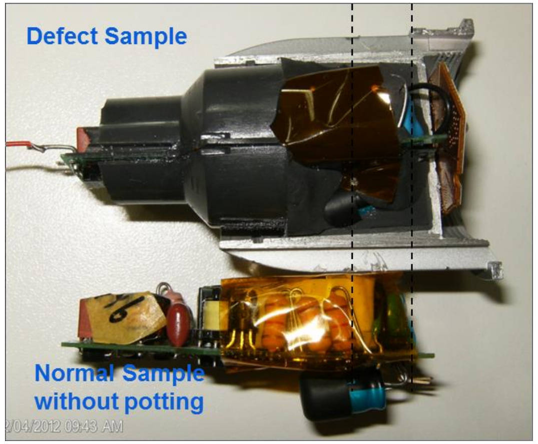
The industry is flooded with unknown failure modes

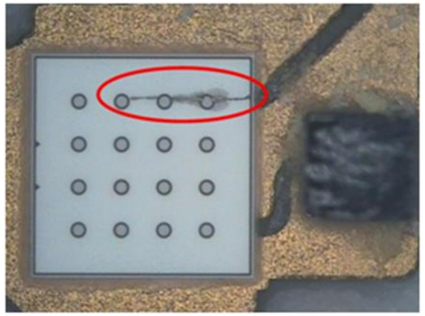
Due to extension of warranties, e.g.

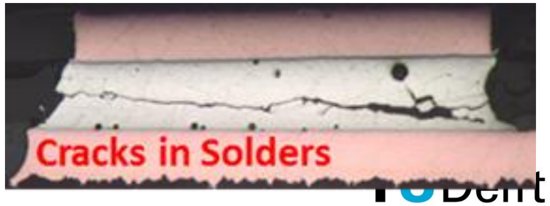
- 7 years for cars
- 10 years for LED Luminaires











Trend towards product reliability diagnostics & prognostics

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Classical Reliability

- Based on standardized (Q&R) tests
- Experimental failure analysis
- Usage is information is assumed -> not fully predictive (can only predict system reliability for failure modes that are known)

Data Analytics

- Looks for correlations of signals to failure (real usage conditions)
- Lots of signals needed due to black box approach ‘big data’
- Improved prediction horizon

Prognostics and health monitoring

- Build physics-based models to understand data (beyond correlation)
- Characterize black box leading to tailored set of signals ‘less data’
- Full prediction of possible failures using real usage conditions

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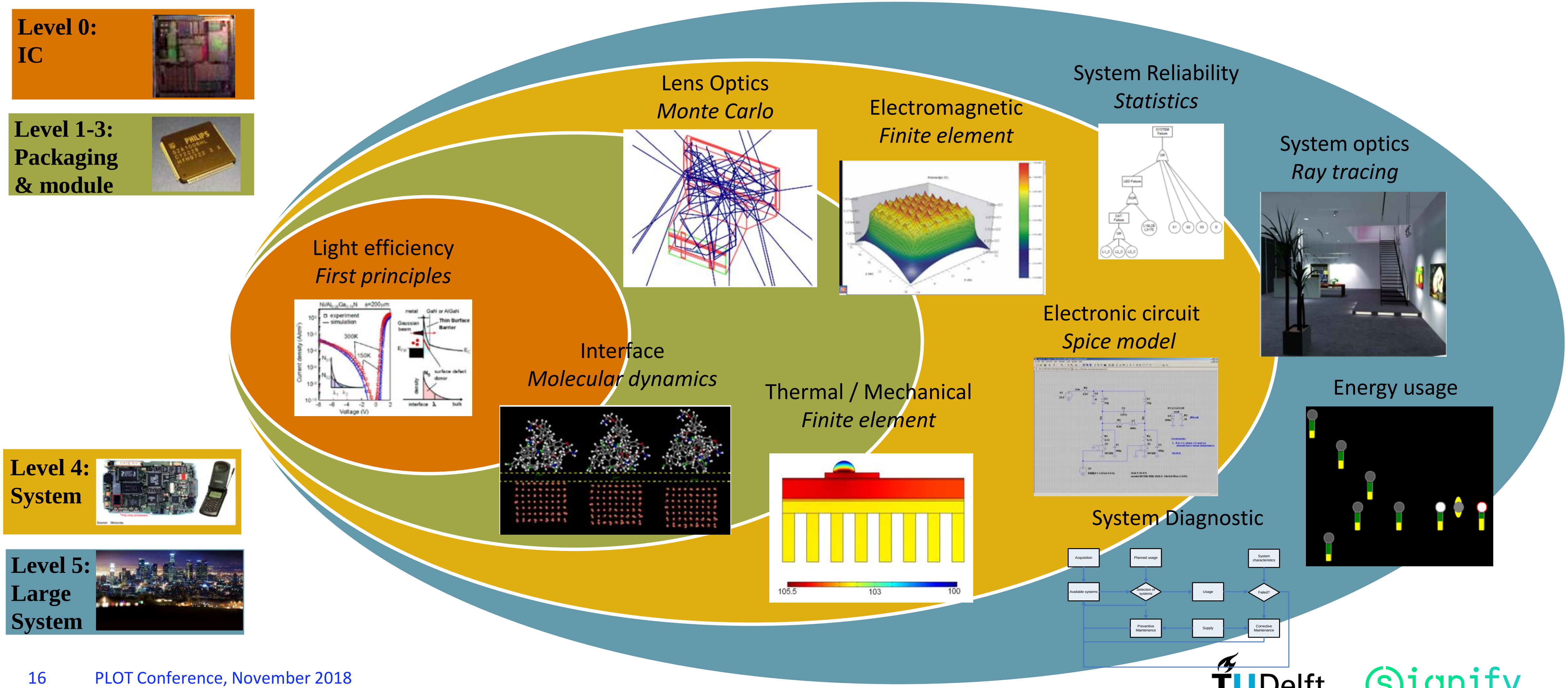
Extensive use of a multi-scale / physics modeling framework



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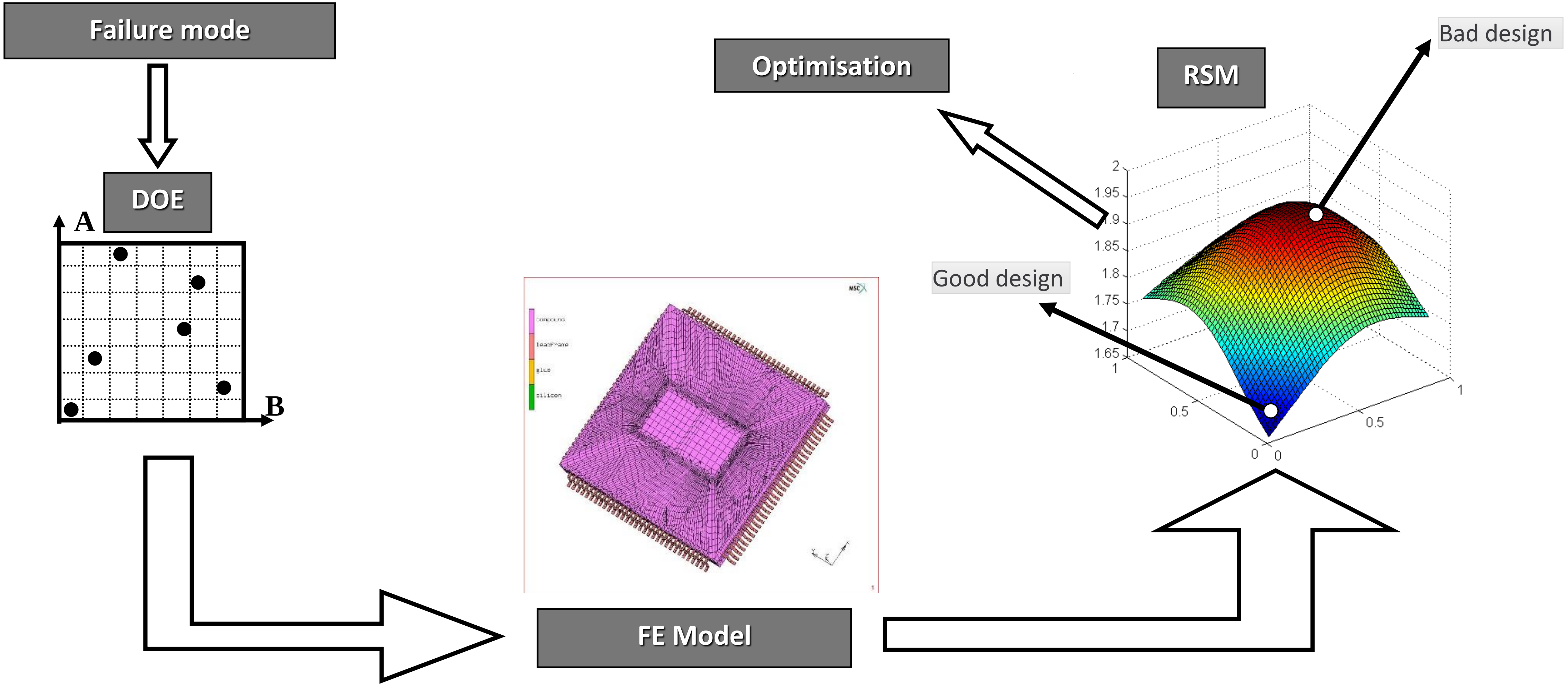
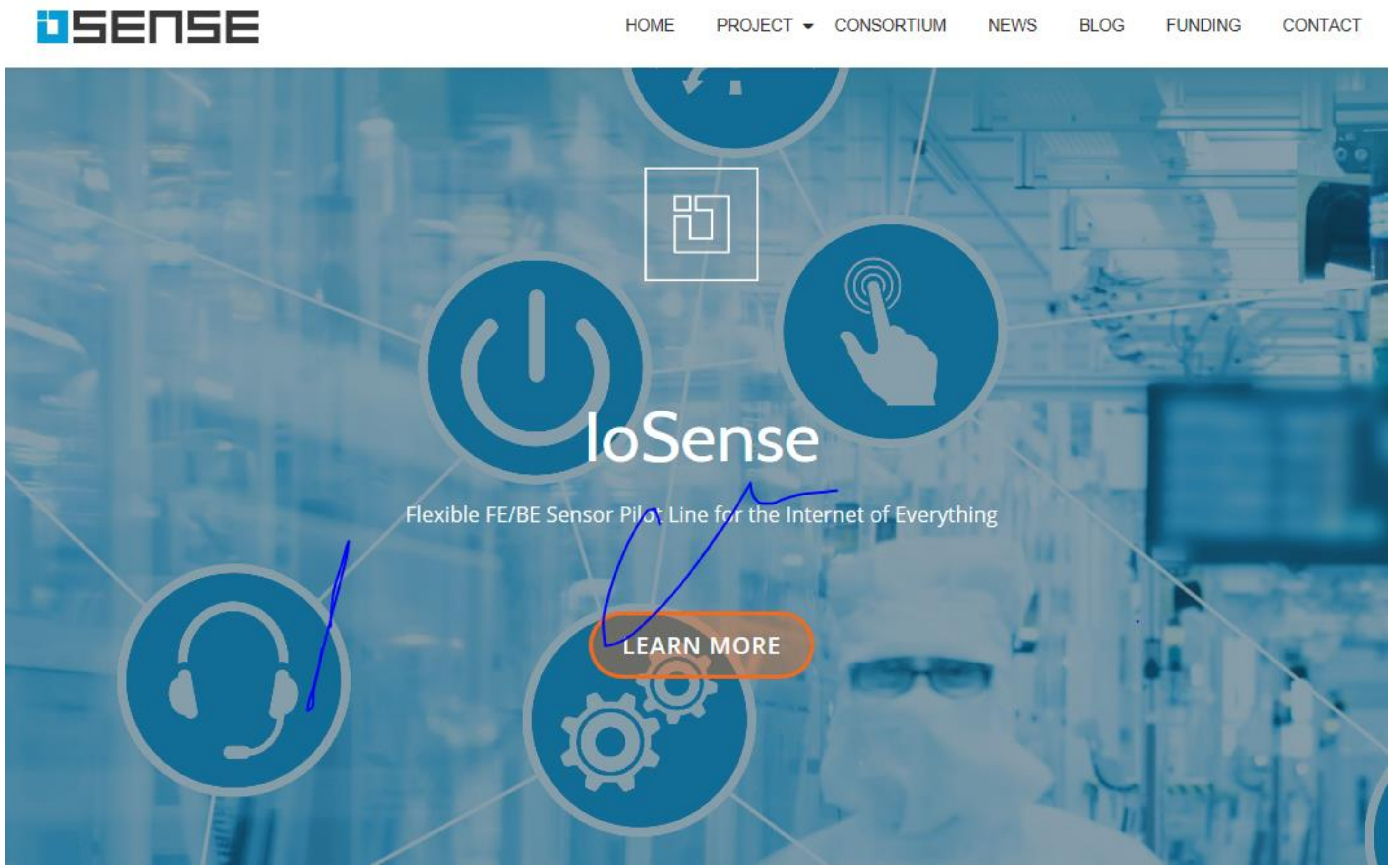
Example: Product optimization by FEM - RSM



Development is done in Open Innovation mode

IoSense: European funded project, http://www.iosense.eu/



The Future

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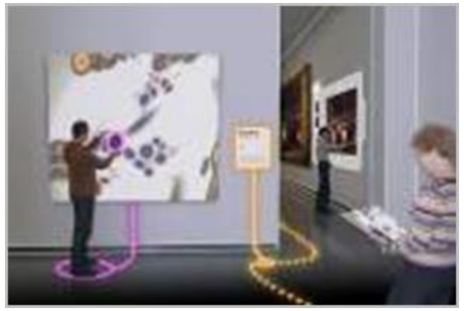
User experience is key differentiator

In the future, customer satisfaction will be put in the center

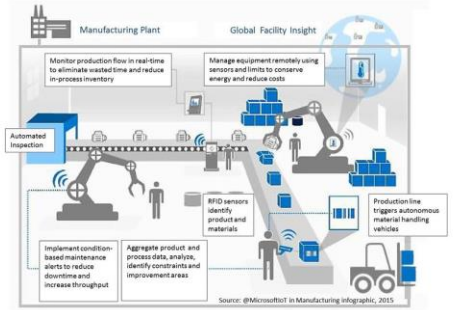

Smart City
- 100% safe city
- Personalized city
- Living city
- Context aware information


Smart Tansport
- 100% safe car
- Autonomous driving
- Car office/cinema
- Context aware information


Wellbeing
- Personalized wellness
- Wellness stimulation
- Dream on demand
- Neuro stimulation
- Drug delivery systems
- Social presence env.




Smart Entertainment
- Open-space gaming
- Virtual movie experience
- Interactive surfaces
- Public gaming
- HD-3d Home cinema
- Interactive fashion




Smart Factory 5.x
- 100% automation
- Fully digitized
- Act on demand
- 100% safe environments

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Reliability becomes availability

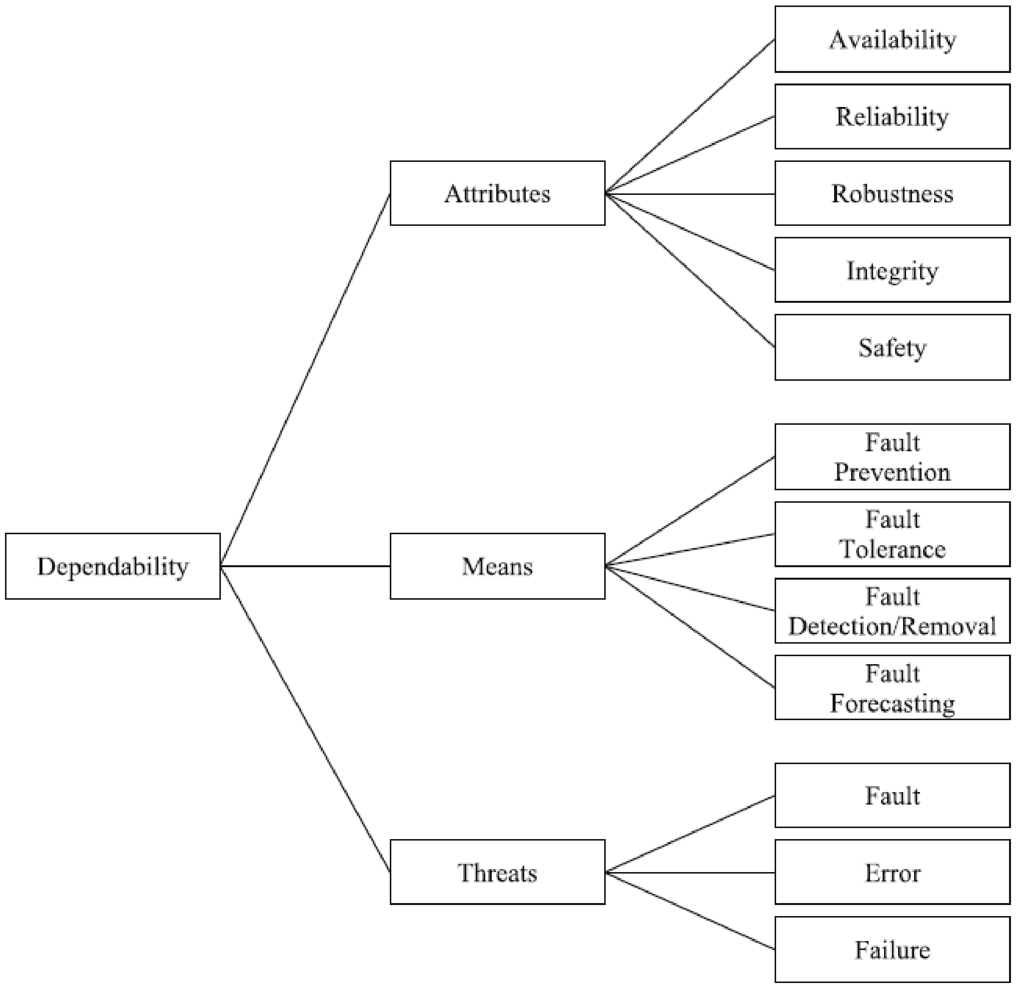
As to promise the customer known values of reliability

Definition

> *The degree to which a system, subsystem or equipment is in a specified operable and committable state at the start of a mission, when the mission is called for at an unknown, i.e. a random, time*

The dependability tree: a measure of system’s availability, reliability and maintainability

Component Reliability moves to System Software Reliability



Digital Twin: the next step

Digital twins are software representations of assets and processes that are used to understand, predict, and optimize performance in order to achieve improved business outcomes

Three elements: a data model, a set of analytics or algorithms, and knowledge

By knowing current context and predicting future state of a digital twin, you can effectively monitor, simulate, and control an asset or process, and optimize lifecycles whether it is online or offline

Gartner has listed digital twin technology among its Top 10 Strategic Trends for the past two years. In addition Gartner predicted that, by 2021, *half* of all large industrial companies will have adopted digital twin technology.

The gain of digital twin technology

Combines data analytics with physics-of-failure

See: GE Digital Twin or Wikipedia

Or the other 444M hits on Google

Digital twin

From Wikipedia, the free encyclopedia

Digital twin refers to a digital replica of physical assets (physical twin), processes, people, places, systems and devices that can be used for various purposes.[1] The digital representation provides both the elements and the dynamics of how an Internet of things device operates and lives throughout its life cycle.[2] Definitions of digital twin technology used in prior research emphasize two important characteristics. Firstly, each definition emphasizes the connection between the physical model and the corresponding virtual model. Secondly, this connection is established by generating real time data using sensors.

Definitions of digital twins used in existing literature

Definition	Authors
"A Digital Twin is an integrated multiphysics, multiscale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin"	Glaessgen & Stargel, (2012)
"Coupled model of the real machine that operates in the cloud platform and simulates the health condition with an integrated knowledge from both data driven analytical algorithms as well as other available physical knowledge"	Lee, Lapira, Bagheri, an Kao, (2013)
"digital twin is a real mapping of all components in the product life cycle using physical data, virtual data and interaction data between them"	Tao, Sui, Liu, Qi, Zhang, Song, Guo, Lu & Nee, (2018)
"a dynamic virtual representation of a physical object or system across its lifecycle, using real-time data to enable understanding, learning and reasoning"	Bolton, McColl-Kennedy, Cheung, Gallen, Orsingher, Witell & Zaki, (2018)
"Using a digital copy of the physical system to perform real-time optimization"	Söderberg, R., Wärmefjord, K., Carlson, J. S., & Lindkvist, L. (2017)
"A digital twin is a real time digital replica of a physical device"	Bacchiega (2017)

Outcomes enabled by digital twins

93-99.49%
Increased reliability in less than 2 years

40%
Reduced reactive maintenance in less than 1 year

75%
Reduced time to achieve outcomes

$11M
Avoidance in lost production by detecting and preventing 3 failures

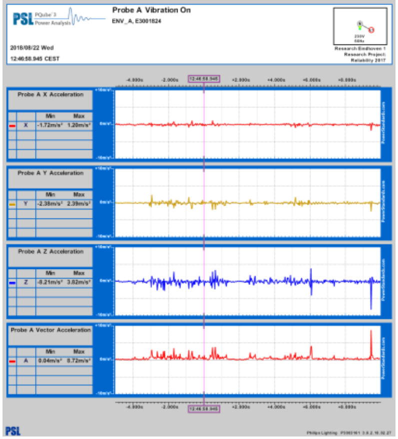
Example: health monitoring of luminaires

Health monitoring module

2018

Physical Environment ⟷ Digital Environment

On-line data generation



Algorithms

$$\Theta(t) = \exp(-\alpha t^{\beta})$$

$$L_{70} = (-\ln(0.7)/\alpha)^{1/\beta}$$

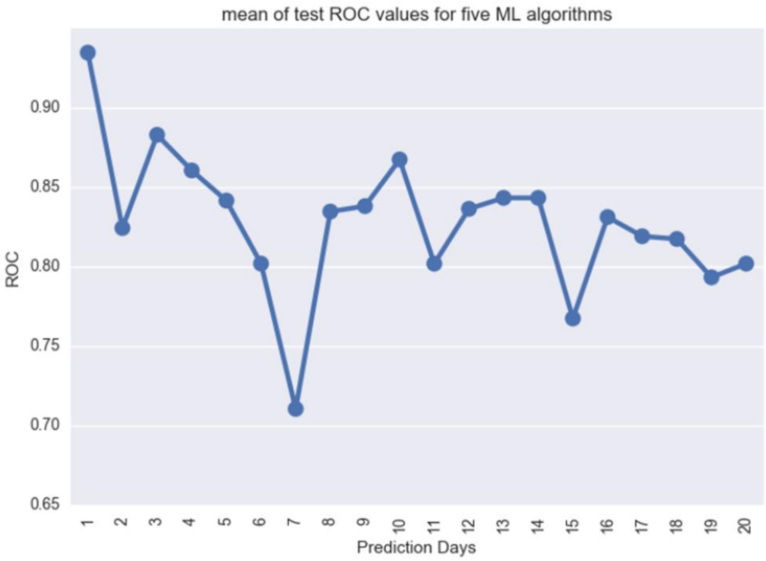
$$\Phi_{\text{fromexit}} = (1 - R_e - A)\Phi_{\text{toexit}}$$

$$AF = \left(\frac{\Delta T_1}{\Delta T_2}\right)^n$$

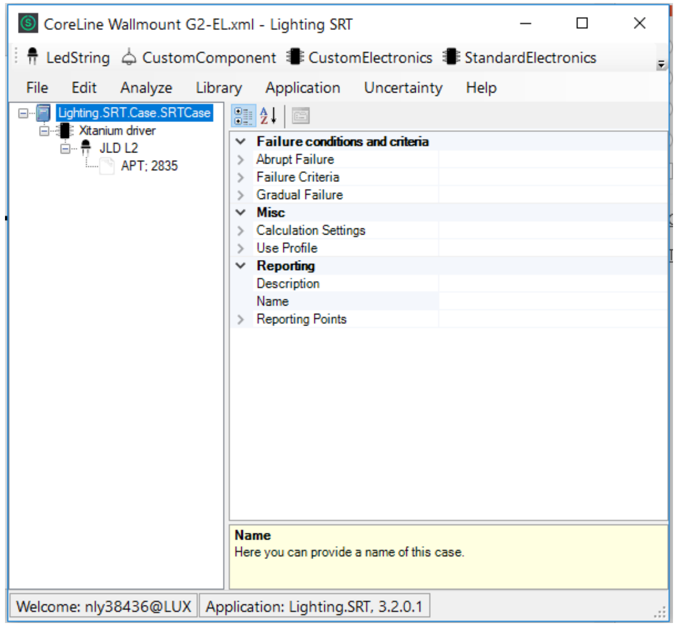
$$\alpha = C \exp\left(\frac{-E_a}{k_B T_s}\right) I^n$$

$$\alpha_{app} = \alpha_0 * AF = \frac{\alpha_0}{(I_{f0})^n} exp\left(\frac{-Ea}{kT_{j0}}\right)(I_f)^{-n} exp\left(\frac{Ea}{kT_j}\right) = C_{cat}(I_f)^{-n_{cat}} exp\left(\frac{B_{cat}}{T_j}\right)$$

Determine degraded performance



System reliability tool



How do we get there?

Further development of present methods rather than a revolutionary new approach:

Key topic 1: Physics of Failure (PoF)

Deeper understanding of possible failure modes, its associated mechanisms and the inherent testing-to-failure to find them. In stead of testing to comply, the engineers need to look for the weakest link.

Key topic 2: Design for Reliability (DfR)

Develop digital twin technology, which is no more than just a mathematical model of a physical object.

Key topic 3: Prognostics and Health Management (PHM)

Create a more predictable product based on real-world usage conditions

Search for early warning failure indicators for those weakest links

The roadmap

World-wide activity in semiconductor-based industries

Achievements			
Year	PoF	DfR	PHM
3	• Physical failure analysis techniques applicable during the loading situation • Realistic material and interface characterisation depending on actual dimensions • Variability and uncertainty: multi-objective optimization, stochastic methods, I4.0	• Chip / board / module / system interaction: standard definition for tool chain and data exchange format across supply chain • Virtual testing – design of very harsh tests for component characterisation • Metamodeling and Model Order Reduction: complex behaviour of a system incl. stochastic data	• Self-diagnostic tools and robust control algorithms • Artificial intelligence and machine learning: usability in daily engineering tasks • Prognostics using hybrid approach (combined data and model driven approach)
5	• Comprehensive understanding of top-25 failure mechanisms incl. prediction models • Digital twin: Understanding of field related failure modes • PoF models considering aging	• Mathematical modelling of competing and/or super-imposed failure modes • Failure prevention and avoidance strategies • Virtual prototyping – DfX – building blocks • Metamodeling and Model Order Reduction: non-linear behaviour using machine learning • Automation of reliability assessment	• Hierarchical and scalable health management architectures, integrating diagnostic and prognostic capabilities from the components to the complete device • Monitoring test structures and/or monitor procedures • Development of schemes and tools using machine learning technique and AI for PHM
10	• Accelerated testing methods based on mission profiles and failure data • Multi-mode loading based on mission profile • Digital twin: Local/global key failure indicators	• Metamodeling and Model Order Reduction: Multi-objective optimization (design, manufacturing, costs) • Model library (digital twin) of the device for DfX • DfX optimization schemes and tools based on AI & machine learning algorithms	• Identification of early warning failure indicators and development of methods for predicting the remaining useful life of the device • Digital twin: In-situ state of health evaluation • Big sensor data management (data fusion, find correlations, secure communication)

Reliability & Prognostics

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1. Introduction

The history of reliability as we know it now goes back to the 1950s, when electronics played a major role for the first time [1, 2]. Now, 70 decades later, the electronic industry is facing a continuous increase of early and wear-out failures with accompanying consequences. Figure 1 depicts the struggle for the different high-tech industries, ranging from harsh environment suitability to long lifetime and warranty coverage. Nowadays, products with high failure rates are logged on the web leading to bad reputation for a company. In many ways, reliability is part of everyday life and part of consumer expectations. The word reliability is extensively used by the general public and the technical community, as illustrated by the following: there are over 3000 published books whose title or keywords contain the word reliability; the web of science lists some ten thousand technical papers with 'reliability' as a keyword (since 1973); and the popular search engine Google lists over 12 million occurrences of 'reliability' on the world wide web. Here, the following definition of reliability is used:

Reliability: The probability that a system will perform its intended function under stated conditions for a specified period of time without failures.

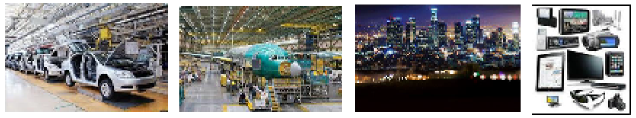

Figure 1: The major concern of high-tech industries: direct finance loss; delayed product release; liability and reduced consumer confidence. Each industry has its own key reliability focus areas, as listed here.

2. Current state of the art & challenges

When creating new (integrated) functionalities and/or increasing the performance, the concerns of reliability and functional safety shall be accounted for right from the start of the development. This avoids wrong choices, which otherwise, may lead to costly and time-consuming repetitions of several development steps or even major parts of the development. In worst case, unreliable products could enter the market with dramatic consequences for customers and supplier. The main challenges in the electronic industry are related to [3, 4]:

- Continuous growth in number, complexity, and diversity of the functional features, of the devices and components integrated as well as of the technologies and the materials involved in each product;
- Increase in reliability and safety level to be achieved by the products, which will simultaneously and more frequently be deployed to ever harsher environments;
- Decrease in time-to-market and cost per product due to the stronger global competition;
- Higher complexity and depth of the supply chain raises the risk of hidden quality issues.

Take-home message

Those who fail to learn from history are doomed to repeat it

Sir Winston Churchill

SEMINAR

Trends and Challenges in Reliability: from Components to Systems

What the Researchers are Suggesting and the Companies have yet to do

May 9-10 2019, Eindhoven the Netherlands

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